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ANALYSIS AND CONSOLIDATION OF ARCHITECTURAL PLASTERS FROM ÇATALHÖYÜK, TURKEY

Evan Kopelson

A THESIS

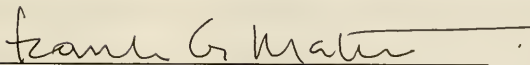
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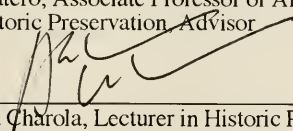
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ABSTRACT

This thesis is the product of a literature review and experimental research program directed toward determining the effectiveness of consolidation of architectural plasters as part of the comprehensive conservation program for Çatalhöyük, a Neolithic period site in Turkey. Çatalhöyük is one of the preeminent archaeological sites in the world. It represents the first periods of agricultural production, animal domestication, and urbanization. It also possesses wall paintings and plaster reliefs which are unique artifacts of the artistic and creative abilities of Neolithic societies. Interpretation of the site relies on a holistic understanding of the architecture. Thus conservation of all aspects of the architecture, including the wall plasters and relief plasters found throughout the site, is critical to the current excavation and research work which is being done under the direction of Ian Hodder of Cambridge University.

The first part of the research was to characterize the structure of the plasters and to identify the microfabirc of the plaster layers. This was accomplished through a series of techniques, including microscopic examination of the bulk samples, cross-sections, and thin-sections and scanning electron microscopy with energy dispersive spectroscopy. Laboratory tests were also carried out to determine other physical and mechanical properties of the plasters, such as particle size distribution and content of soluble salts, organic, and acid-soluble material. The plasters were found to be earthen plasters composed primarily of expansive clays and calcareous particles. These plasters were applied frequently and repeatedly to horizontal and vertical surfaces and were sometimes molded into reliefs or painted.

A great variety of natural and synthetic materials have been used by conservators to consolidate architectural materials. Based on the results of the characterization and

analysis of the Çatalhöyük plasters, three classes of consolidants were tested: an acrylic resin, an epoxy resin, and three ethyl silicate consolidants. The effectiveness of their consolidating potential were evaluated based on the increase in resistance to abrasion and wet/dry cycling imparted to the plasters, the depth of penetration into the plasters, and the changes caused to their optical properties by the consolidants. It was determined that an ethyl silicate monomer is the most promising consolidant due to its substantial depth of penetration, minimal change to optical properties, and tangible increase in hydrophobicity and abrasion resistance of the plasters.

Because laboratory conditions can never duplicate field conditions, laboratory research must be evaluated in conjunction with field testing to have validity. The research that was completed under ideal conditions in the laboratory was compared to findings from field testing carried out in August and September of 1996. From these results it is clear that although the tested consolidants provide some degree of consolidation, they cannot satisfactorily conserve the plasters when used alone *in situ*. More research is necessary in order to decide what consolidating material is the most effective means of conserving the architectural plasters of Çatalhöyük and what role the consolidant will play in the entire conservation sequence, including the detachment of mural paintings.

Chapter One: Introduction

More than any other excavated archaeological site, Çatalhöyük has formed the basis for our current understanding of Near Eastern prehistory. Its significance as one of the earliest known permanent settlements in the world and the potential insight it gives us regarding the artistic, intellectual, technological and social organizational accomplishments of the first stages of the Neolithic period make it a potent symbol of human achievement during the sixth and seventh millennia BC. First excavated by James Mellaart from 1961 to 1965, the site is currently being reexcavated under the direction of Ian Hodder of Cambridge University as part of a 25 year project begun in 1993.

The retention and therefore conservation of the architectural elements, including the wall plasters, mural paintings, and reliefs, is one of the primary concerns of the present effort. Based on the importance of the site to our understanding of early human behavior and interaction, and the desire for *in situ* interpretation, architectural conservation is included as a major component of the current project. Efforts to recover, conserve, and present to the public the paintings, plaster reliefs, and architecture of Çatalhöyük are presently underway. This thesis represents the findings of a research program designed to characterize the wall and relief plasters of Çatalhöyük and the laboratory and field experimentation undertaken to evaluate needed consolidation treatments for these materials both in the laboratory and at the site.

1.1 Çatalhöyük, a Neolithic site in Turkey

Located about 1,000 meters above sea level in the open expanse of the Konya Plain of southern Turkey, is the archaeological site of Çatalhöyük. The site sits in the center of fertile wheat fields near the Çarsamba River, approximately 11 kilometers north of Çumra and 40 kilometers southeast of the city of Konya. (Figure 1). Hills and mountains surround the Konya Plain, among which the Taurus Mountain chain to the south is the most notable. Hot dry summers and severe winters are typical in the area, with rainfall usually occurring in the winter and spring months.¹

The archaeological site consists of two mounds: the west mound, dating to the late Neolithic and early Chalcolithic period (ca. 5600 BC to 4900 BC) is a circular mound with a diameter of approximately 400 meters and a maximum height of 7.5 meters above the level of the plain, and the east mound, an oval approximately 500 meters in length and 300 meters in width with a height of 17.5 meters above the plain.² The east mound, where nearly all excavation and subsequent research, including this thesis, have been focused, dates to the early Neolithic period with subsequent Iron Age and Hellenistic pits. Of the 32 acres, only one acre had been excavated prior to the current excavations. (Figure 2).

The earliest confirmed levels of occupation date to ca. 6750 BC,³ making the site one of the earliest known examples of the shift from an economy based on hunting and gathering to one based on the domestication of plants and animals. Up to 15 occupation levels have been identified in the Neolithic mound of Çatalhöyük. The city had an

¹ Ian A. Todd, *Çatal Hüyük in Perspective* (Menlo Park, CA: Cummings Publishing Co., 1976), 7-12.

² Ibid., 7-8.

³ Ibid., 104-105.

extensive regular layout of structures which consisted of attached building units and open areas on each occupation level. (Figure 3). Each building unit had its own four walls which were connected to the walls of adjacent units with earthen infill. (Figures 4 and 5). The wall paintings and plaster reliefs found in various units also contribute to the importance of the site, ranking among the earliest monumental art of the period.

Building units at Çatalhöyük are made of wood, sun-dried mud-brick, reeds, and plaster. The structural features are built of sun-dried brick, sometimes reinforced with timber posts. The mud brick is shaped into standardized sizes which vary between occupation levels but tend to stay consistent within levels. For the early levels, such as Levels VI A and VI B, most of the mud brick units are 32 x 16 x 8 centimeters. In later layers, the units are larger, such as the 65 x 37 x 8 centimeter units of Level II.⁴ In some levels, the mud bricks are over 100 cm in length. The roofs are formed of bundles of reeds sandwiched between a thick mud covering and a fiber mat on top of wooden beams. Entry into each unit is through an opening in the roof. Plaster is used to cover most of the vertical and horizontal surfaces of the room. The building units display a consistency in plan, being one-story rectangular dwellings, usually with a small storeroom attached. Inside, two raised platforms are often found along the east wall and a higher bench along the south wall. A hearth is also usually at the southern end of the room and most rooms also have an oven. Mellaart, in describing the interior of the rooms, stresses the importance of conscientious design, as seen in the consistent pattern of architectural features used in a “system of plaster ribs, engaged posts (plastered and

⁴ James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 55-56.

frequently painted red) for vertical differentiation in combination with horizontal offsets, so that each room bore a number of panels and recesses.”⁵

Some of the rooms constructed of the same materials with a comparable plan can be differentiated by such features as plaster reliefs, wall paintings, cattle horns set into benches, rows of bucrania, and *ex-voto* figures. (Figure 6). Mellaart has interpreted these more elaborate building units as shrines.⁶ A total of 48 shrines were identified in the excavated portion of Çatalhöyük, with 15 more probable or possible shrines, out of a total of 166 rooms.⁷

Mellaart has suggested that the shrines and religious art “constitute the community’s most important archaeological contribution” and has proposed a hierarchy of shrines based on the differences in size and decoration.⁸ By this he is referring to the significant role he sees Çatalhöyük as having in the world art historical tradition as well as the religious meaning that he understands the features of the shrines to indicate. Mellaart has maintained that religion at Çatalhöyük was created and ruled by women.⁹ Part of this interpretation is based on the fact that the anthropomorphic figure most frequently found in the shrines of Çatalhöyük is the female deity which Mellaart has titled ‘The Great Goddess.’ Animal figures and symbolic patterns, such as rows of human breasts, also appear in relief in plaster.

In a more recent interpretation of Çatalhöyük, Ian Hodder, the current excavator, has offered a new hierarchy of building unit types and features which affects the

⁵ James Mellaart, “Excavations at Çatal Hüyük: First Preliminary Report, 1961,” *Anatolian Studies* 12 (1962): 48.

⁶ James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 78.

⁷ *Ibid.*, 80.

⁸ James Mellaart, “A Neolithic City in Turkey” (San Francisco: W. H. Freeman Co., 1964), 9. Reprinted from *Scientific American* (April 1964).

⁹ *Ibid.*, 9.

conception of religious as well as secular activities. According to Hodder, the hierarchy outlined by Mellaart is part of a continuum across building units from simple dwelling units, called “houses,” with almost no decoration and rare burials at one extreme to decidedly religious units, called “shrines,” with a great amount of decoration and rich burials at the other extreme. Both house and shrine rooms, Hodder contends, would have been used for both domestic and ritual purposes but to varying degrees.¹⁰ Decoration which Mellaart has associated with life, such as scenes of birth, rows of breasts, and red hand prints are usually found on the west walls of shrines, and painted representations of death, fox, weasel, and vulture skulls, and the color black are more common on the east walls. Hodder cautions against an overly simplistic and dualistic interpretation of society at Çatalhöyük, however. Vulture beaks and animal skulls, which Hodder has connected to death through contextual associations such as paintings of vultures, are found inside of molded plaster breasts. This indicates a more complex symbolic representation of social order which can be interpreted in many different ways, as Hodder has argued.¹¹ Although Mellaart and Hodder disagree on the specific meaning of decoration at Çatalhöyük, they both acknowledge that the more elaborate rooms are “shrines” and that these shrines contain features that were ritually created and maintained as part of a system that sought to attach symbolic meaning to social organizations.

One of the artistic forms integral to the inferred social-symbolic system seen at Çatalhöyük are the rich plaster reliefs. Mellaart has reported that plaster reliefs appear at the earliest level of occupation that has thus far been excavated, Level X, dating to ca. 6300-6500 BC. They first appear as simple animal heads but later become figures in

¹⁰ Ian Hodder, “Contextual Archaeology: An Interpretation of Catal Hüyük and a Discussion of the Origins of Agriculture,” *Institute of Archaeology Bulletin*, no 24 (1987): 44.

¹¹ *Ibid.*, 43-56.

sunken relief and projecting reliefs of whole animals, including their heads, bodies, and limbs. “Goddesses” and symbolic patterns such as breasts and horns first appear in Level VII, ca. 6200 BC. Plaster reliefs features in the shrine rooms appear to end by Level IV, ca. 5900, after which no evidence of them is found.¹² Mellaart attributed ritual significance to the plaster reliefs and wall paintings:

That wall-paintings and plaster reliefs of goddesses and animal heads had a ritual significance and were not purely decorative (or in the case of animal-heads substitutes for hunters’ trophies) is shown very clearly by the fact that wall-paintings were covered by layers of whitewash after they had served their ritual function and that plaster-reliefs were made ritually harmless by the obliteration of the face, hands and feet when a shrine was abandoned. Many of the animal heads were similarly defaced or broken off and frequently only the outline survives or their original position is marked by a broad scar on the wall. Some of these heads were built into new walls, evidently to bring protection to the building. Only in shrines destroyed by a sudden fire have many plaster reliefs survived more or less intact, but here the destruction has again obliterated the faces of the goddess reliefs.¹³

Before being destroyed, most plaster reliefs had been replastered many times, indicating frequent preservation of the animal and human forms.¹⁴ Todd has found that the majority of reliefs were not decorated with painting,¹⁵ in contrast to Mellaart’s assessment that “plaster reliefs are frequently painted and the two techniques are evidently complimentary.”¹⁶ Reliefs are found on the north, east, and west walls, and more rarely on the south walls of rooms.¹⁷ Hodder has assigned a domestic role to the south end of

¹² James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 99-101.

¹³ *Ibid.*, 82-83.

¹⁴ *Ibid.*, 82.

¹⁵ Ian A. Todd, *Çatal Hüyük in Perspective* (Menlo Park, CA: Cummings Publishing Co., 1976), 50.

¹⁶ James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 101.

¹⁷ *Ibid.*, 102-103.

the rooms, based on the presence of hearths and ovens here and on the entrance of the rooms being located here.¹⁸ Thus, in both Mellaart's and Hodder's analysis, the symbolic meaning of the decoration and architecture of Çatalhöyük is intricately connected to central aspects of social and cultural life at the site.

In addition to the impressive plaster reliefs at Çatalhöyük, the floors and walls of the houses and shrines were covered with plaster. Applied as smooth layers on vertical and horizontal surfaces, these plaster layers were sometimes painted but most often left undecorated. (Figure 7). Although often unpainted, the plaster might have served a decorative function by enhancing the interior environment of the rooms. It also had a pragmatic role, intended or not, protecting the mud brick from elements of weathering. The many layers of plaster indicate that it was often replaced, perhaps with ritual significance.

1.2 Plaster as an architectural element

Architectural plaster is a plastic material which upon drying usually forms a mechanical or chemical bond with its substrate to give a hard, smooth, relatively insoluble surface.¹⁹ Plaster is a secondary nonstructural material which is applied for protection and decoration. By providing a continuous barrier against water, wind, and biological growth, plasters protect the structural core from agents of deterioration. Plasters also have a decorative value which can be aesthetic or symbolic.

¹⁸ Ian Hodder, "Contextual Archaeology: An Interpretation of Catal Hüyük and a Discussion of the Origins of Agriculture," *Institute of Archaeology Bulletin*, no 24 (1987): 48-49.

¹⁹ The term "plaster" is used here to denote both interior and exterior surface finishes. In the United States, interior finishes are commonly called "plaster" and exterior finishes are often called "stucco." "Render" refers to an applied surface finish and is synonymous with "plaster" in this thesis.

All plasters are composed of a binder which determines the main properties, aggregate which gives bulk to the mixture and controls shrinkage, and additives which provide bulk and may be used to enhance certain properties of the plaster. Water is necessary in the preparation of plaster to give plasticity. Because the amount of water used affects the preparation and curing of plasters, ambient conditions of temperature and humidity are an important factor during plastering.²⁰ The availability of materials used in the mixing and manufacture of plaster will determine the type of plaster. Plasters traditionally used in pre-industrial architectural contexts have been typed into three main groups according to composition: earthen plasters, gypsum plasters, and lime plasters.²¹

Earthen plaster is made of clays or marls with particles of various sizes used as aggregate. When water is added to the clay or marl soil, the layered platelets of clay will form parallel strata and the soil will become plastic. Because of similarity of composition, earthen plasters usually have relatively good adhesion to mud brick substrate. The granulometry, the clay type, the addition of additives such as straw, and the amount of water used in the mixture determine the durability and performance of the plaster.

Gypsum plaster is manufactured by heating gypsum rock or alabaster ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) to temperatures from 150°C to 400°C . This drives off some of the water from the calcium sulfate dihydrate and forms calcium sulfate hemihydrate, or plaster of Paris ($\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$). If water is added to this it will rehydrate the mixture and form a hard crystalline gypsum plaster. Studies of Neolithic plaster production in the

²⁰ Frank Matero, "A Programme for the Conservation of Architectural Plasters in Earthen Ruins in the American Southwest: Fort Union National Monument, New Mexico, USA," *Conservation and Management of Archaeological Sites* 1, no. 1 (1995): 4.

²¹ Maria Isabel G Beas, "Traditional Architectural Renders on Earthen Surfaces," (master's thesis, University of Pennsylvania, 1991), 6-13.

Near East show that gypsum plaster is most commonly found at archaeological sites near the Tigris and Euphrates Rivers and farther east.²²

Lime plaster is made by calcining material such as limestone, marble, dolostone, or seashell which contains a high percentage of calcium carbonate (CaCO_3) or magnesium carbonate (MgCO_3) by heating it up to 900°C , then slaking the resultant calcium or magnesium oxide (CaO or MgO) in water to make a pasty composition. Aggregate such as sand is often added to the pasty material to provide bulk and control shrinkage. The mixture can be applied directly to architectural surfaces where it will react with the carbon dioxide (CO_2) in the atmosphere and solidify, reforming calcium or magnesium carbonate.

Evidence from Çatalhöyük indicates that a variety of materials were used at the site to make plaster which was then applied as even layers on wall and floor surfaces or molded into different shapes to form reliefs. Limestone, marly soils, and gypsum veins are all located in the Konya Basin within close proximity of the site. Answers to technical questions such as which raw materials were used and how they were processed are important to an understanding of the cultural and social interpretation of Çatalhöyük as well as for their characterization for conservation treatments. Information about the composition of plaster at Çatalhöyük can be used to demonstrate how technological knowledge can be used in socially and culturally meaningful ways.

Ancient plaster technology is informative to scholars today in a variety of ways depending on the viewpoint from which they approach the topic and the goal of their research. Archaeologically, the use of lime plaster has been proposed as one of the

²² W. David Kingery, Pamela B. Vandiver, and Martha Prickett, "The Beginnings of Pyrotechnology, Part II: Production and Use of Lime and Gypsum Plaster in the Pre-Pottery Neolithic Near East," *Journal of Field Archaeology* 15, no. 2 (Summer 1988), 236-237.

characteristics of a site that may be diagnostic of the Neolithic period.²³ Plaster appears in many forms at many Near Eastern Neolithic sites. To manufacture and apply lime or gypsum plaster requires a greater degree of technological and social modification than was demonstrated before the Neolithic period.²⁴ Higher firing temperatures, and thus more fuel, are needed to burn the raw material. Gourdin and Kingery claim that the development of lime plaster “seems to have been nearly simultaneous with the appearance of villages and true architecture.”²⁵

When considered from the vantage of material culture, plaster may be valuable in determining the aesthetic, functional, and symbolic role of such finishes and the importance that a society places on them. The plaster reliefs of Çatalhöyük have been used not only to differentiate between room functions, but also to demonstrate the high degree of artistic creativity during the Neolithic period. The plaster used on flat architectural surfaces, sometimes painted to enhance the architectural space of the room, may have a meaning beyond modern ability of interpretation.

Viewed from the standpoint of conservation, plaster is often seen as expendable relative to other found materials. Because it is the first surface to come into contact with the environment and thus suffers the worst of its effects, the condition of a plaster surface is often judged too ephemeral or deteriorated to conserve. A conservator today may find it easier and more economical to lose or replace plaster rather than conserve it. The multiple layers of plaster forming the wall surfaces and reliefs at Çatalhöyük indicate that

²³ W. H. Gourdin, “A Study of Neolithic Plaster Materials from the Near and Middle East,” (master’s thesis, Massachusetts Institute of Technology, 1974).

²⁴ Gary O. Rollefson, “The Uses of Plaster at the Neolithic ‘Ain Ghazal, Jordan,” *Archeomaterials* 4, no. 1 (Winter 1990): 33.

²⁵ W. H. Gourdin and W. D. Kingery, “The Beginnings of Pyrotechnology: Neolithic and Egyptian Lime Plaster,” *Journal of Field Archaeology* 2, no. 1/2 (1975): 133.

during the Neolithic period, people also chose to replaster rather than to conserve existing plaster surfaces, perhaps as part of ritual practice related to room use and world view.

1.3 Conservation of the plasters from Çatalhöyük

Because of the cultural significance that archaeologists and conservators have seen in the ancient plasters of Çatalhöyük, it is desirable in this case to conserve the plaster. The surviving plasters of Çatalhöyük are evidence of the concrete actions and decisions made during prehistory. *In situ* conservation is necessary because when exposed to the hot dry air upon excavation, the plaster layers detach from their substrate, delaminate between layers, and flake apart. By removing the insulating earth that has protected the site for thousands of years, archaeological excavation subjects the plasters to deleterious environmental changes. In order to conserve the plasters as evidence and as an integral part of the interpreted site of Çatalhöyük, a method of impeding the deterioration mechanisms must be devised. As part of the conservation of the remarkable wall paintings that are characteristic of the site, the plaster substrate and paint layers must be stabilized.

1.3.1 Previous conservation work

The fragile condition of the exposed surface finishes was immediately apparent during the previous excavations of Çatalhöyük in the 1960s. In published field reports, Mellaart commented on the state of preservation of some of the plaster reliefs and wall paintings. Although the mud brick walls were well preserved, allowing accurate interpretation of the building plans and dimensions, the plastered surfaces were not always as intact. In some cases, the plaster reliefs were intentionally destroyed during the

period of occupation. Mellaart suggested that the “plaster-reliefs were made ritually harmless by the obliteration of the face, hands and feet when a shrine was abandoned.”²⁶ In other cases, the poor condition of the plasters was due to deterioration during thousands of years of internment and subsequent alteration once unearthed. Todd wrote that “when exposed to the hot dry summer air the wall plaster dried and hardened very quickly, thus making it much more difficult to remove the plaster layers overlying the requisite painted surfaces.”²⁷

Although the condition of the surface finishes during the 1960s excavations is occasionally brought up in published material, there is little mention of conservation treatments. Mellaart mentioned removing two centimeters of “unburnt plaster from the walls” in order to expose the paintings below.²⁸ This reveals the early preference to expose wall paintings. Todd offered a more complete description of the conservation program:

The building-by-building excavation of the site had the advantage that each structure could be treated as a unit, and the decoration of entire walls could be exposed, conserved, and removed at the same time... The cleaning and conservation of extensive well-preserved wall paintings at Çatal Hüyük presented problems which had never before been faced on a large scale on a Near Eastern prehistoric excavation. The discovery of wall paintings was totally unexpected, and conservation measures had to be instituted immediately to ensure their preservation.²⁹

Conservation measures consisted primarily of removing wall paintings and plaster reliefs for storage and display at museums. In order to stabilize the wall paintings and plaster

²⁶ James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 82.

²⁷ Ian A. Todd, *Çatal Hüyük in Perspective* (Menlo Park, CA: Cummings Publishing Co., 1976), 19.

²⁸ James Mellaart, “Excavations at Çatal Hüyük, 1962: Second Preliminary Report,” *Anatolian Studies* 13, (1963): 67.

²⁹ Ian A. Todd, *Çatal Hüyük in Perspective* (Menlo Park, CA: Cummings Publishing Co., 1976), 19.

before removal from the site, the plaster was hardened with polyvinyl acetate glue and wrapped with gauze bandages. The plaster and wall paintings were then encased in wooden boxing and removed with one or two inches of their mud brick substrate.³⁰

Although the decorative and functional importance of non-relief wall plasters was acknowledged by Mellaart and other researchers at the time of the previous excavation and mural painting conservation work, there are no reports of attempted treatments on these wall plasters. Although yearly field reports, several articles, and a book written by Mellaart exist as published material, Mellaart's field notes do not. The primary published source for descriptions of treatments carried out during excavation are Todd's brief passages. The undecorated wall plasters constitute an integral feature of the architecture of Çatalhöyük and are thus an important component in the current conservation work which includes characterization and analysis of wall and relief plasters as well as the assessment of treatments for the plasters.

1.3.2 Current conservation work

In order to effectively conserve the plasters, consideration of their composition, the environment and conditions of the site, and the interpretation of the architecture is required. In order to understand the materials and technologies associated with the plasters of Çatalhöyük, their physical and chemical properties have been investigated. The structure and composition of the plasters have been examined on a range of levels to understand the material in all of its aspects.

Following from this characterization and analysis, consolidation of the plasters was considered. The friable condition of the plasters and the probable need for intralayer

³⁰ James Mellaart, personal communication, 16 September 1996.

detachment of mural paintings necessitate the use of a consolidant which will allow sufficient stabilization and strengthening of the plasters. The use of consolidants to improve the strength of the plaster finishes and prepare the surfaces for transport off site if necessary, depending on excavation needs, was evaluated. An assessment of the condition of the plasters *in situ* was used to determine whether treatment will be necessary, how much strengthening is desired if needed at all, what the sequence of treatment will be, and whether the plasters can be conserved *in situ* or whether they will have to be removed from their setting. Emergency stabilization of the detaching plasters may be necessary before any other action can be taken or it may be found that the plasters cannot be conserved at all without relocation. As part of the current conservation work, chemical consolidants which restore intergranular cohesion were evaluated to determine which will strengthen the plasters the most effectively given the conditions of the plasters and environment of the site with the least change in overall properties.

There are a number of considerations which are particular to the conservation of plaster because of the nature of the material.³¹ In comparison to most stones, on which the majority of consolidation research has been focused, plaster is relatively permeable. This means that it is more vulnerable to liquids and gases such as water carrying solubilized salts, conservation treatments, and water vapor. In addition, due to its secondary role as an architectural element, plaster is in constant contact with other materials that comprise the walls, ground, and sometimes roof of a structure. These other

³¹ Mauro Matteini, "In Review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments," in *The Conservation of Wall Paintings: Proceedings of a Symposium Organized by the Courtauld Institute of Art and the Getty Conservation Institute, London, July 13-16*, edited by Sharon Cather (Marina del Rey, CA: Getty Conservation Institute, 1991), 137.

elements contribute to the dynamic process of physical, mechanical, and chemical change which occurs in the system.

The effects of plaster consolidation on other conservation processes should also be considered. Plaster consolidation will affect other treatments such as preconsolidation, grouting, cleaning, and the detachment of mural paintings at Çatalhöyük. Plaster treatment will also affect natural processes such as weathering and water transmission. It is desired that the chosen treatment have as little effect on these properties as possible. The treatment should also allow for future maintenance, performance, and retreatability.

As part of an on-going archaeological excavation, the conservation treatment designed for Çatalhöyük must take into account other issues specific to archaeological sites. As levels of the site are being excavated, the architectural material of the site must be removed. Thus, procedures for recording and conserving the architecture are being devised along with means of detaching, lifting, and moving architectural features. Although it is desirable to conserve architectural elements *in situ* to preserve the unity and integrity of a site, temporary and permanent relocation of architecture may be necessary. Methods of conserving the plasters may be affected by these actions, and conversely, may affect the other phases of research and treatment.

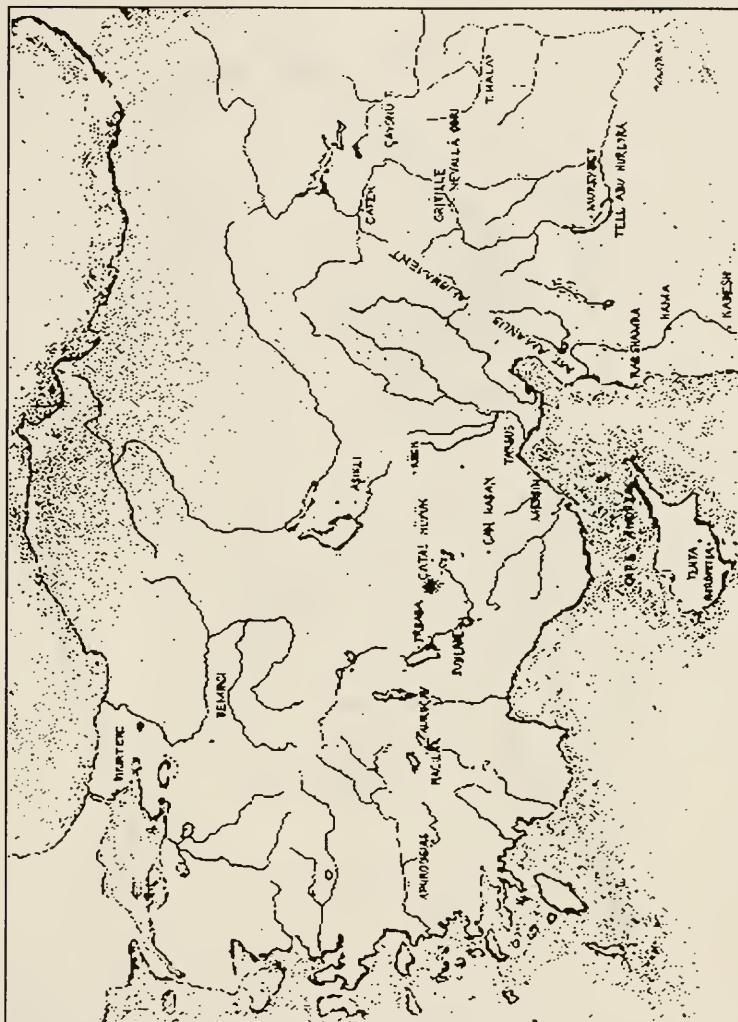


Figure 1: Map of Turkey showing Neolithic sites. From Mellaart, James, Udo Hirsch, and Belkis Balpinar, eds. *The Goddess from Anatolia*, Volume 2. Milan: Eskenazi, 1989.

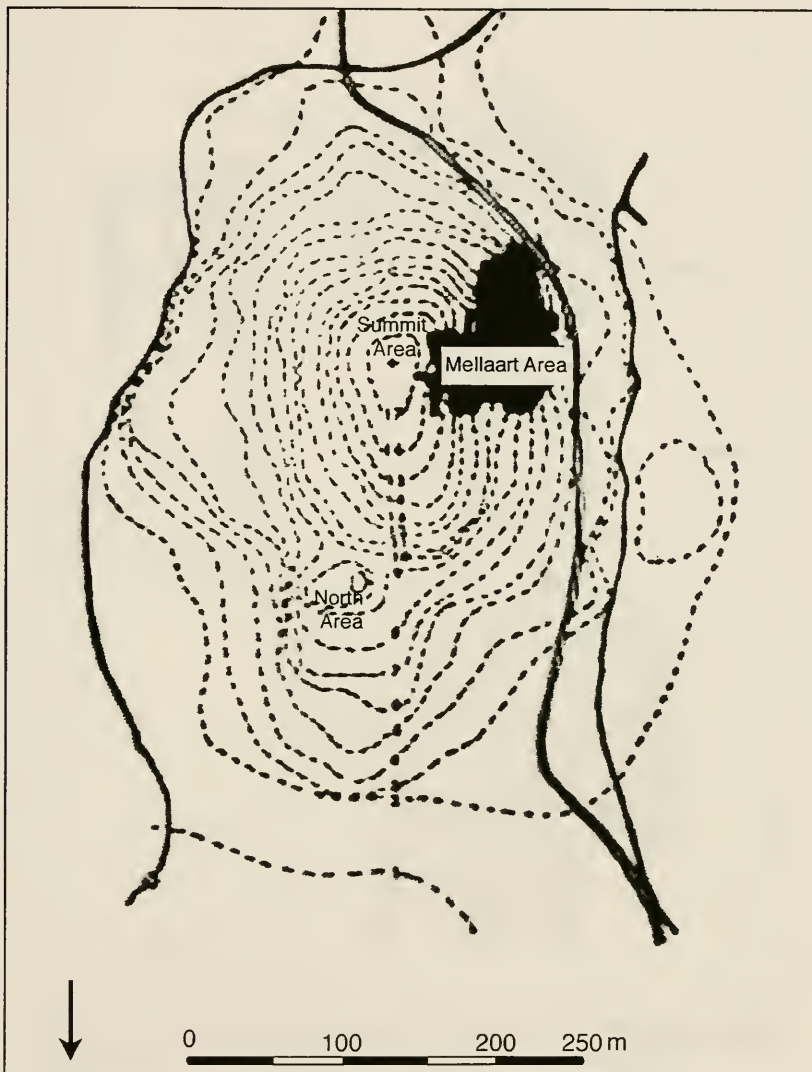


Figure 2: Site plan of Çatalhöyük showing the extent of the 1960s excavation in black and the three areas currently under excavation. From Mellaart, James. *Çatal Hüyük, A Neolithic Town in Anatolia*. New York: McGraw-Hill Book Co., 1967.

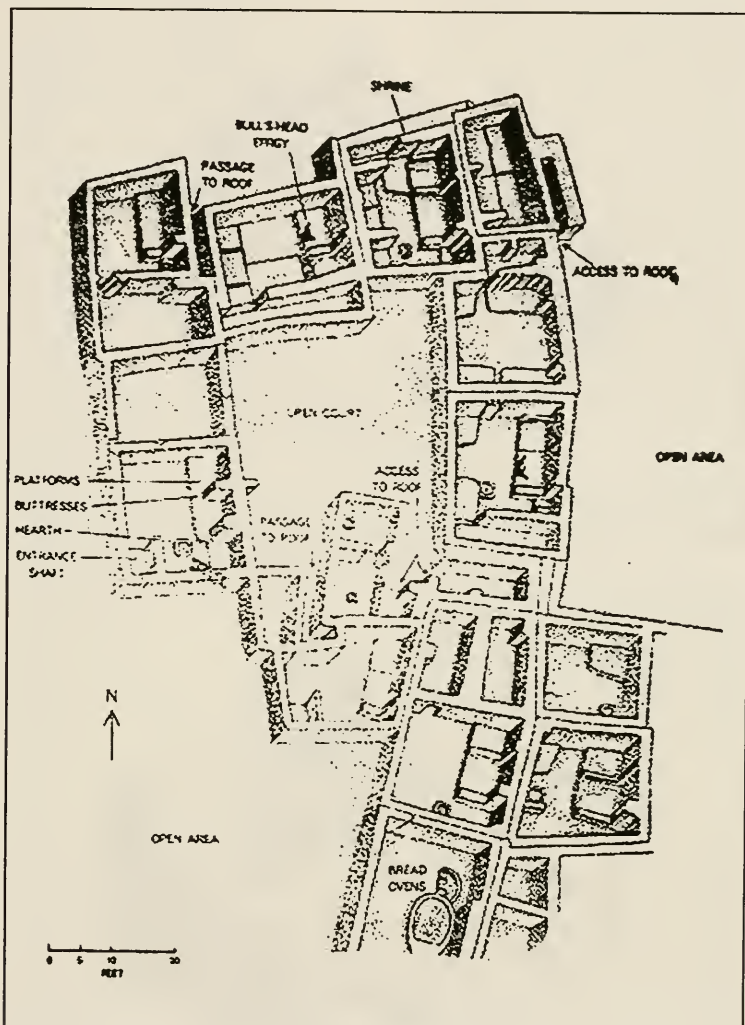


Figure 3: Reconstruction of Level 5 showing typical architectural features. From Mellaart, James. "A Neolithic City in Turkey." Reprinted from *Scientific American* (April 1964).

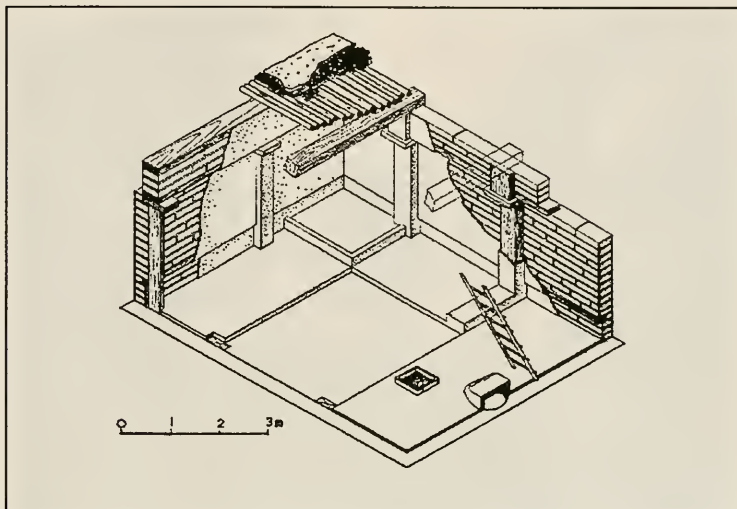


Figure 4: Reconstruction of a house. From Mellaart, James. *Çatal Hüyük, A Neolithic Town in Anatolia*. New York: McGraw-Hill Book Co., 1967.

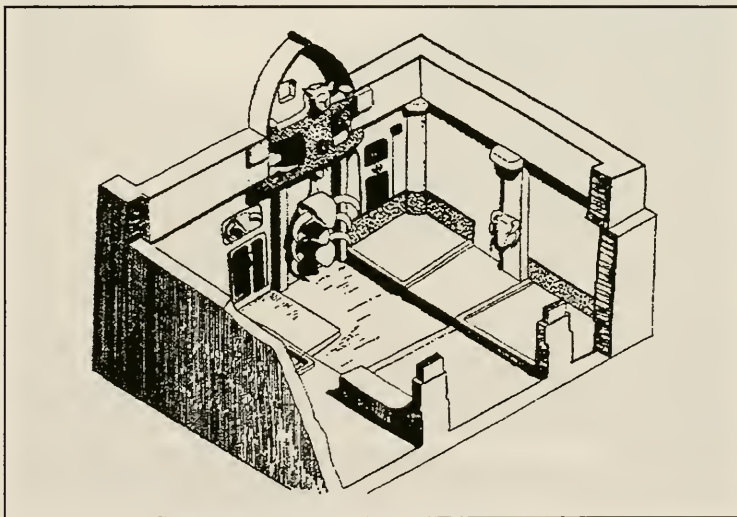


Figure 5: Reconstruction of shrine VI.B.10. From Mellaart, James. *Çatal Hüyük, A Neolithic Town in Anatolia*. New York: McGraw-Hill Book Co., 1967.



Figure 6: Photograph of the east wall of Shrine VI.A.7, showing plastered walls and reliefs. From Mellaart, James. *Çatal Hüyük, A Neolithic Town in Anatolia*. New York: McGraw-Hill Book Co., 1967.



Figure 7: Photograph of a bull wall painting. From Mellaart, James. "Çatal Hüyük—The World's Oldest City." *Illustrated London News*, 28 May 1966, 26-27.

Chapter Two: Examination, Analysis, and Characterization

The application of any conservation treatment should be based on an understanding of the material to be treated and its aesthetic, technological, and cultural context. Thus, characterization and analysis are performed in order to know structure and composition and how materials are used within a system. *Characterization* is a description of the distinguishing properties of a material, usually given in terms of its physical, mechanical, and chemical properties. *Analysis* is the determination of constituent types and amounts and their structural relationships in a material.

In the case of the plasters from Çatalhöyük, characterization and analysis were carried out on representative samples to determine the compositional properties of the plasters, to describe how the different components were put together into a working system, and to identify changes that have occurred over time. These determinations are useful in answering archaeological questions related to the source of the plaster materials and the technology of plaster manufacture. They are also critical to the understanding of alteration and decay mechanisms and to the consideration of conservation measures associated with the deterioration of the plasters.

2.1 Methodology

A review of the literature relating to characterization and analysis of plaster in general and archaeological plaster specifically was undertaken. This investigation allowed a better understanding of the techniques which would be appropriate in the characterization and analysis of the Çatalhöyük plasters and the methodology that would be required for evaluation of conservation treatments. (Appendix A).

Increased attention to plaster as a material worthy of study has resulted in the development of a systematic, and thus holistic, approach to plaster characterization and analysis. The importance of a well-established methodology for the study of plasters has been widely recognized among conservators, archaeologists, and material scientists only within the last 20 years. Past methods of limited examination have been replaced by more complete studies which seek to understand the composition and structure of plasters on a number of levels.

The characterization and analysis of plaster depends on an understanding of the structure and composition of the materials used in its manufacture. The most complete methodology for the examination of architectural plasters is the holistic approach suggested by Kingery.¹ In order to understand plaster, or any other archaeological artifact, Kingery recommends following a series of analyses in order to evaluate different structural levels. The first level of analysis draws from contextual evidence and is found in field reports and the archaeological setting. Examination of the object's gross physical properties can provide information on its cultural associations. Visual examination of the macrostructure of the object can also reveal how an object may have been manufactured

¹ W. David Kingery, "Microstructure Analysis as Part of a Holistic Interpretation of Ceramic Art and Archaeological Artifacts," *Archeomaterials* 1, no. 2 (Spring 1987): 91-99.

and what materials were used. Analysis then proceeds to the microscopic level in order to determine what materials were used and how based on the microstructure, type, size, shape, and arrangement of the components. This is accomplished with optical and electron microscopy. The crystalline or glassy structure of some materials can be revealed through analytical techniques which employ diffraction phenomena. Finally, elemental composition can be determined by spectroscopic examination.

The methodology proposed by Kingery provides a basic outline of the different structural levels that should be examined in order to have a complete understanding of the composition, manufacture, use, and perhaps even the symbolic or functional reason of an archaeological object. The development of the methodology grows out of thesis research by W. H. Gourdin to investigate the role of pyrotechnology in Neolithic societies of the Near East and complementary work by Kingery and other researchers to answer similar research questions.² The application of the various types of analysis will depend on the nature of the research questions which are posed. Recent investigations of plaster in archaeological research have focused on answering questions of technological capabilities, dating, cultural relations, and provenience. Techniques most commonly used in these investigations are optical microscopy, electron microscopy, and chemical analysis.

An analytical technique that has proved particularly useful in the study of archaeological plasters is micromorphology. *Micromorphology* is a branch of soil science used to describe, interpret, and measure the components, features, and fabrics of soils and

² William Hugh Gourdin, "A Study of Neolithic Plaster Materials From the Near and Middle East," (Master's thesis, Massachusetts Institute of Technology, 1974); W. H. Gourdin and W. D. Kingery. "The Beginnings of Pyrotechnology: Neolithic and Egyptian Lime Plaster." *Journal of Field Archaeology* 2, no. 1/2 (1975): 133-150; and W. David Kingery, Pamela B. Vandiver, and Martha Prickett. "The Beginnings of Pyrotechnology, Part II: Production and Use of Lime and Gypsum Plaster in the Pre-Pottery Neolithic Near East." *Journal of Field Archaeology* 15, no. 2 (summer 1986): 219-244.

related materials.³ Although thin sections have been used for over 100 years to describe geological features (petrography), undisturbed soils in thin sections were first described in 1938.⁴ Micromorphology was first applied to an archaeological context in the 1950s and has since experienced shifting levels of popularity as a method of answering geoarchaeological research questions.⁵

Depending on the purpose of the characterization and analysis, each level of examination may not be necessary. Gordon Brown suggests that for the simple characterization of plasters, concretes, mortars, and stuccos as may be needed for archaeological research, simple wet chemical tests and microscopic examination are usually sufficient.⁶ Tests of the unit weight, absorption, compressive strength, Mohs hardness, lime content, depth of carbonation, and aggregate composition can be easily carried out and can give important information about the source, type, and use of materials in a sample based on their physical and chemical properties. Many of these tests are similar to those performed in the analysis of soils by soil scientists. Wet chemical analysis can also be used to qualitatively determine the content of organic material and soluble salts. Brown suggests that microscopic examination using transmitted or reflected optical light will provide additional insight into the nature of the material.⁷

The conservator is interested in not only knowing the structure and composition of a material but how these have altered over time. Thus, documenting the condition of

³ This definition of "micromorphology" is based on that given in P. Bullock et al., *Handbook for Soil Thin Section Description* (Wolverhampton: Waine Research Publications, 1985), 9.

⁴ Marie Agnus Courty, Paul Goldberg, and Richard Macphail, *Soils and Micromorphology in Archaeology* (Cambridge: Cambridge University Press, 1989), 5.

⁵ *Ibid.*, 5.

⁶ Gordon E. Brown, "Testing of Concretes, Mortars, Plasters, and Stuccos." *Archeomaterials* 4 (1990): 185-191.

⁷ *Ibid.*, 185-191.

plasters is usually the first step in plaster characterization. The stratigraphy of the surviving plaster should be investigated to determine the original application and temporal succession of layers and the structural and compositional characteristics of the materials. In addition, treatment recommendations based on determinations of the physical, mechanical, and chemical properties of the plaster and its condition may be a part of the analysis.

In the case of the plasters from Çatalhöyük, the focus of the investigation is the composition and structure of the plasters as a function of the time of their production and application as manifested by the many layers of material, and as a function of the intervening period of time up to the present as revealed by the physical, mechanical, and chemical properties of the plasters. The methodology used to characterize and analyze these layers is modeled on Kingery's outline of archaeological artifact analysis.

documentation: Analysis begins with a review of field reports and other documents relating to the plasters and their context. This includes a review of the general nature of earthen plasters and the specific findings of geological studies for the Konya Basin.

bulk samples: Examination of the bulk samples is used to identify evidence of manufacturing processes such as burnishing marks and to select representative samples for further investigation.

cross sections and thin sections: Cross sections and thin sections prepared from the samples are characterized in order to determine micromorphology, including the macrostructure and microfabric. *Macrostructure* is the visible form of a material and the spatial relations that exist within it. The stratigraphy and the presence of distinctive features can be identified using cross sections. *Microfabric*

is the constituent parts that are only discernible on a microscopic level. Micromorphological examination of the thin sections can provide information about the macrostrata of the plasters, including properties such as layer thickness, color, texture, and evenness, as well as data concerning the microfabric, such as granulometry and porosimetry of the individual strata.

scanning electron microscopy: Scanning electron microscopy with energy dispersive x-ray analysis is used to examine the composition and determine the chemical structure of the plasters. Scanning electron microscopy allows examination of the microstructure at higher magnifications than light microscopy and when used with energy dispersive spectroscopy gives the semi-qualitative elemental composition.

wet chemical analysis: Wet chemical testing is performed in order to qualitatively identify the presence of acid-soluble, organic, and soluble salt material. In addition, the granulometry of the plasters is quantitatively determined using sieving and wet gravimetric analysis. These properties are a necessary part of the characterization as they contribute to an understanding of the manufacture of the plasters and their alteration over time. Any consideration of treatments will rely on this information.

2.2 Earthen plaster as an architectural element

Earthen plaster, commonly termed clay or mud plaster, is the most common material used to cover earthen walls.⁸ Its advantages as an economical, durable coating

⁸ Clough Williams-Ellis, John Eastwick-Field, and Elizabeth Eastwick-Field, *Building in Cob, Pise and Stabilized Earth*, (London: Country Life Limited, 1919), 103.

for earthen construction are as appealing today as they were in the past when people first built permanent settlements. Soil is manipulated to form a slurry which can then be easily applied to both interior and exterior architectural surfaces. As with other types of plasters, availability of material, ease of application, resistance to impact damage and cracking, sufficient adhesion to the substrate, and durability are the principle requirements of earthen plasters.⁹

The properties of earthen plaster and its effectiveness as a render depend on its composition. Soil is a heterogeneous mixture made up of particles of diverse composition, shape, and size which represent various parent rocks. One way to classify soils is by grain size, or granulometry. The following grain size convention, based on American Society for the Testing of Materials (ASTM) standards, are used in the current study:¹⁰

clay:	particles smaller than 0.002 mm (2 μ m).
silt:	particles between 0.002 mm and 0.02 mm.
fine sand:	particles between 0.02 mm and 0.075 mm.
coarse sand:	particles between 0.075 mm and 4.75 mm
gravel:	particles between 4.75 mm and 76.2 mm.

The amount of each type of particle varies from place to place, but ideally clays make up 20-25% of an earthen plaster, sand is approximately 40-45% of the mixture, and the

⁹ Maria Isabel Beas, "Traditional Architectural Renders on Earthen Surfaces," (master's thesis, University of Pennsylvania, 1991), 6

¹⁰ "D 422: Standard Test Method for Particle-Size Analysis of Soils," (Philadelphia: ASTM, 1993) and "D 653: Standard Terminology Relating to Soil, Rock, and Contained Fluids," (Philadelphia: ASTM, 1993).

remaining portion is silt.¹¹ Clays, silt, and sand each impart a characteristic property to the plaster.

Clays are compositionally defined as hydrated aluminosilicates resulting from the chemical leaching of the main minerals in rock, especially micas, feldspars, and pyroxenes.¹² Alumina and silica molecules are held together by ionic bonds to form sheets, with water held between the layered sheets. Due to the property of clays known as cation exchange capacity, ions can be adsorbed on the surface of a clay particle or absorbed between layers of the mineral structure.¹³ In addition, mixed layer minerals can form through the substitution of specific mineral layers in the crystallographic structure of a clay particle with other mineral species.¹⁴ The layered structure of clays imparts plasticity so that clays can be easily shaped when wet and will retain the shape upon drying. Some clays are very susceptible to swelling or shrinking in the presence or absence of water, and are thus termed “expansive.” A high clay content will increase the chances of cracking upon drying and may also cause poor adhesion to the substrate. Clays generally act as the binding medium in earthen plaster, holding together the more inert, larger grain fraction.

Silts are basically small sand particles when considered from a physical and chemical point of view.¹⁵ Because of their smaller size, they increase internal friction

¹¹ S. N. Mehrotra, “Non-erodable Mud Plaster on Mud Wall for Rural Houses,” *Building Research Note* 12, (June 1983), 3.

¹² Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide*, translated by Albert Gompers and Janice Schilderman (London: Intermediate Technology Publications, 1994), 25-26.

¹³ Bruce Velde, “Composition and Mineralogy of Clay Minerals,” chapter 2 in *Origin and Mineralogy of Clays: Clays and the Environment*, edited by Bruce Velde, 8-42 (Berlin: Springer-Verlag, 1995), 15-16.

¹⁴ *Ibid.*, 35-37.

¹⁵ Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide*, translated by Albert Gompers and Janice Schilderman (London: Intermediate Technology Publications, 1994), 25.

within the soil and thus impart stability. Films of water between silt particles means that, like clays, they help to bond together the components in earthen plasters. Silts help to provide bulk to the plaster.

Sand is usually made up of particles of silica and other eroded minerals.¹⁶ Sand has a high degree of internal friction but very little cohesion. When used in plaster, sand is an aggregate which bulkens the material and provides hardness, durability, and shrinkage control. Because of its minimal water adsorption, sand in soil will not expand and contract.

Clay or mud plaster is usually applied as two coats: a ground coat and a finish coat. The ground coat fills cracks and levels out any inconsistencies in the underlying support. Fibrous material and other natural additives can be used in the mixture to provide mechanical resistance, thickening, and water repellency to the plaster or to slow down its curing rate. The finish coat is made up of finer material which can be applied as a very thin layer. It may be burnished or smoothed out by hand alone or with the aid of a stone, animal skin, or float. Dampening the surface during curing will reduce the likelihood of shrinkage cracks occurring.

The use of earthen material as a coating over mud brick surfaces plays both a protective and a decorative role. It has the advantage of containing materials that are compatible with the substrate so that natural bonding is increased and water vapor is freely exchanged between the earthen substrate and the atmosphere. This reduces the chances of the plaster detaching from the substrate. Burnishing or polishing the plaster surface not only increases its hardness and resistance to moisture by aligning the clay plates, but also imparts an aesthetic value.

¹⁶ Ibid, 25.

2.3 Documentation

2.3.1 Archaeological field reports

In addition to surveying the methodology of plaster analysis and the general topic of earthen plasters, specific research into the nature of the Çatalhöyük plasters was undertaken in order to determine which materials were likely to be found in the samples. This began with the examination of archaeological documents and field reports.¹⁷ Thus, the first step in the characterization of the Çatalhöyük samples was to research Mellaart's published field reports and soil studies from the Konya region.

The architecture of Çatalhöyük consists of units built with sun-dried mud brick, using either a fine clay mixed with chopped straw or sandy clay, in wood framed structures.¹⁸ Materials such as wooden poles, reeds, and clay were layered to form a roof covering. The units each have four individual walls and contain features such as ovens, hearths, and raised sitting and sleeping platforms. Many of these features and the interior walls were plastered and some were also painted.

One of the few references to the material nature of the plaster found at Çatalhöyük occurs in the field report published after the first season of excavation in 1961. At this point, Mellaart suggested that the plasters used to cover architectural features within rooms were manufactured from earthen materials, perhaps selectively chosen or modified to have the correct consistency for plaster: "All these features [oven, kiln, fire box, bench] are carefully plastered in a white or creamy clay (*ak toprak*), still widely used by present day villagers, and the plaster of the walls, etc., was smoothed with polishers in

¹⁷ W. David Kingery, "Microstructure Analysis as Part of a Holistic Interpretation of Ceramic Art and Archaeological Artifacts," *Archeomaterials* 1, no. 2 (Spring 1987), 92.

¹⁸ James Mellaart, "Excavations at Çatal Hüyük: First Preliminary Report, 1961," *Anatolian Studies* 12 (1962): 46.

white or green limestone, of which numerous examples have been found.”¹⁹ This one sentence, describes not only the composition and use, but also the application of the plasters. Using the contextual archaeological evidence of the stone artifacts, the plasters were probably applied with the aid of limestone polishing stones.

In a later season of excavation, Mellaart unearthed a room which he labeled the “Red Shrine” based on its striking color. The placement of the plaster in this room as described by Mellaart and the identification of both lime and earthen plasters are of great importance in the current study of the Çatalhöyük plasters:

Although considerably smaller than the ones that succeeded it, this building [VIII.31] was evidently one of the major shrines of Level VIII and differed from all found so far in being provided with a red-burnished lime-plaster floor, twice relaid.

The shrine was of the familiar plan with oven and ladder along the north wall and with wooden posts and platforms as usual, but at a height of about 3 ft. (95 cms.) above the floor a strongly marked horizontal plaster rib ran around the building, and below the rib the walls were painted uniformly red (except the oven). The posts on the other hand would have been white, as were the walls above the imitation beam. Only on the east wall was the panel above the beam painted red between the posts. Below this panel just above floor-level was set a narrow ledge, about 6 in. in height, covered with a red lime plaster which covered the entire floor, including platforms and benches. This lime plaster rested on a layer of fine gravel and was stained a deep red and then burnished; it stopped at the foot of the walls... Along the south side of the building there was no red lime plaster, but a conventional white mud plaster floor, and below this lay a few burials without any funerary gifts. Below the long narrow bench that extended in front of the main north-west platform in the later phases of the building a raised platform, about 2 ft. long, 1 ft. wide and about 8 in. in height was found, resembling a tombstone or altar table in the centre of the room. Immediately adjacent was a rectangular panel of orange lime plaster broken by a circular hole that had been replastered in greenish white clay, an arrangement suggestive of a chthonic

¹⁹ Ibid., 48.

libation hole of the type that before had been found in Aceramic Hacilar II.²⁰

Thus, in addition to the earthen plasters first described at Çatalhöyük, lime may have also been used. Although Mellaart does not offer an interpretation for his attribution or an interpretation for the differentiated use of lime and earth plasters, it is noteworthy that the lime plaster is found on the floor surfaces and that earthen plasters are used in those areas where burial and ceremonial rites have necessitated replastering.

Archaeological interpretations of technological achievement, as with projections of symbolic meaning and world view, should be made with a great deal of precision and caution. Archaeological literature tends to be a bit careless in the use of technological terminology, including the case of describing plasters. Often, as was the case for Çatalhöyük, initial discovery and interpretation in the field is not followed by laboratory analysis. The only basis for calling something lime may be its white appearance or a high carbonate content, both of which are easily described in the field but can lead to misleading conclusions. Thus the term “lime” used in field reports from Çatalhöyük does not necessarily prove the existence of true calcined lime plaster.

Because true lime plaster which has been calcined, hydrated, and recarbonated has the same chemical composition as unburnt calcium carbonate, it is difficult to chemically differentiate between the two materials. The most effective way to verify the presence of true lime plaster is based on the microstructure.²¹ True lime plaster displays spherical particles less than a micron in diameter which cannot be seen using light microscopy but are visible at the higher magnifications of scanning electron microscopy. These tiny

²⁰ James Mellaart, “Excavations at Çatal Hüyük, 1965: Fourth Preliminary Report,” *Anatolian Studies* 16 (1966): 180-181.

²¹ W. David Kingery, Pamela B. Vandiver, and Martha Prickett, “The Beginnings of Pyrotechnology, Part II: Production and Use of Lime and Gypsum Plaster in the Pre-Pottery Neolithic Near East,” *Journal of Field Archaeology* 15, no. 2 (summer 1986): 221.

particles can be used as a determining feature of lime pyrotechnology in some cases, although over time they will coarsen and become less sharply defined making analysis more difficult.

Limited analysis of plaster from Çatalhöyük suggests that the technological ability to manufacture true lime plaster did exist at the site during the Neolithic period and was used, and not only in the Red Shrine. Kingery, Vandiver, and Prickett analyzed one gray plaster sample from a floor of an unknown building level of Çatalhöyük as part of a subsequent larger study on plaster production throughout the Near Eastern Neolithic.²² Using optical microscopy and scanning electron microscopy with energy dispersive x-ray analysis, they concluded that the technology to produce lime plasters, termed “pyrotechnology,” existed and was utilized at Çatalhöyük.

In summarizing the use of plaster at Çatalhöyük, Mellaart has concluded that earthen plasters were used to cover the interior of all rooms and to form the plaster reliefs found in the shrines. The wall plasters were applied as part of a two-coat system with a careful selection of materials: “Mud plaster, supplemented by a finer, thinner, coat of white marly clay obtained from the Pleistocene lake, covers everything except the staircase and was probably renewed on top of the older layer once a year, or more often when necessary.”²³ The basis of this characterization, made nearly 25 years after the 1960s excavation of Çatalhöyük, is not known. The reliefs were formed by applying plaster to a molded clay substrate, sometimes reinforced with plant material: “Whereas the animal heads [in plaster reliefs] are solid and moulded in clay covered with plaster, the

²² Ibid., 224.

²³ James Mellaart, “Çatal Hüyük,” chap. 1 in *Çatal Hüyük and Anatolian Kilims*. Vol 2 of *The Goddess of Anatolia* (Milan: Eskenazi, 1989), 13.

large figures of goddesses were made of plaster moulded on bundles of reeds, the imprint of which is frequently preserved, or on wooden posts, preserved by carbonization.”²⁴

In addition to visually typing the different kinds of plaster used at Çatalhöyük, Mellaart offered a functional explanation for the multiple layers of plaster which are often found on wall surfaces. He suggested that climatic conditions limited replastering activities to once a year. Thus the number of layers of plaster on any given surface can be used to establish a relative age of occupation levels. Radiocarbon dating seems to confirm this hypothesis.²⁵

In conclusion, from archaeological evidence it is likely that most of the plasters used at Çatalhöyük were earthen plasters, but in some areas, true lime plasters may have been used. The soils used in the earthen plaster may come from two different sources or may be from the same source but manipulated in different ways. The fuel requirements necessary for large scale production of lime plasters may have limited their use at Çatalhöyük. The plasters were applied to horizontal and vertical surfaces in many subsequent layers for plain or decorated finishes or molded into figural relief forms.

2.3.2 Soil and geological studies

Because plaster is perceived of as an ephemeral material, its identification in the field is usually not followed by further investigation of its composition and uses. Although mentions of plaster may appear to give qualitative information on the nature of the material, they are often more descriptive than compositional. Thus, before beginning

²⁴ James Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (London: Thames & Hudson, 1967), 101.

²⁵ *Ibid.*, 49-51.

characterization and analysis, other primary information which might give insight into the composition of the plasters should be investigated.

In the case of Çatalhöyük, although Mellaart gives information which can help answer questions related to the physical and chemical properties of the plaster, the initial field reports were not verified or refuted through subsequent characterization and analysis. As part of the archaeological research, Mellaart did not conduct any thorough pedological analyses or soil studies. However, agricultural studies undertaken in the decade following the initial excavation have proven useful in the present characterization and analysis of Çatalhöyük plasters by providing contextual information on the composition of local materials which could have been used in the manufacture of the plasters.²⁶

The clayey composition and high percentages of calcium carbonate are important characteristics of the soils surrounding Çatalhöyük. Gypsum is also present, but in small quantities and isolated locations. A summary of the studies given by Driessen and de Meester indicates that Çatalhöyük lies within an area whose soils have been called Çarsamba fan soils and is adjacent to a region with soils are classified as former backswamp soils. The fan soils are alluvial clays deposited by the Çarsamba River which winds north through the Great Konya Basin as it passes Çatalhöyük. The Çarsamba soils have a uniform, predominantly fine loamy and clayey texture. All of the soil horizons contain between 15% and 20% calcium carbonate. Gypsum seldom occurs, but is in

²⁶ These studies are cited in Todd, who discusses their relevance to research on the environmental history of the site, not as they relate to the material technology. They include T. de Meester, *Highly Calcareous Lacustrine Soils in the Great Konya Basin, Turkey*, (Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation, 1971), N. A. de Ridder, "Sediments of the Konya Basin, Central Anatolia, Turkey," *Palaeogeography, Palaeoclimatology, Palaeoecology* 1 (1965): 225-254, P. M. Driessen and T. de Meester, *Soils of the Çumra Area, Turkey*, (Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation, 1969), and P. M. Driessen, *Soil Salinity and Alkalinity in the Great Konya Basin, Turkey*, (Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation, 1970).

prominent white veins when it does. The Çarsamba backswamp soils have the same origins as the Çarsamba fan soils, but are of a finer size, being deposited farther away from the former rivers. Smectite clay, which exhibits considerable swelling upon contact with water and subsequent shrinking, makes up the major part of these soils. The carbonate content of the backswamp soils is 15% to 20%, and gypsum is found as spots, crystals, clusters, or veins more often than is the case with the Çarsamba fan soils.²⁷

Geological and pedological studies of the area surrounding Çatalhöyük indicate that both limestone and highly calcareous soils found in marl and soft lime deposits would have been readily available to the inhabitants of the site for the manufacture of plaster. A parallel geogenesis of the soils in the Great Konya Basin as given by Driessen and de Meester is recognizable in the Çumra area. The Taurus Mountains which surround the Great Konya Basin consist primarily of limestone. Rivers from these uplands brought coarse and medium textured sediments to the shores of the ancient Konya Lake (Palaeolake Konya) which once covered the Basin floor. Fine-sized particles were either deposited in local depressions or sedimented in the center of the lake as heavy clays and marly soils.²⁸ The lake probably dried up permanently sometime after 11,000 BC in the Early Holocene period based on the observation of fossil-shells from ca. 12,000 to 11,000 BC.²⁹ The portion of the palaeolake nearest to Çatalhöyük, in the

²⁷ P. M. Driessen and T. de Meester, *Soils of the Çumra Area, Turkey* (Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation, 1969), 31-37.

²⁸ *Ibid.*, 5.

²⁹ Oğuz Erol, "The Quarternary History of the Lake Basins of Central and Southern Anatolia," in *The Environmental History of the Near and Middle East Since the Last Ice Age*, edited by William C. Brice (London: Academic Press, 1978), 129-130. Brice (William C. Brice, "The Desiccation of Anatolia," in *The Environmental History of the Near and Middle East Since the Last Ice Age*, edited by William C. Brice (London: Academic Press, 1978, 144, suggests a sequence of events leading to settlement at Çatalhöyük: as the climate became progressively warmer, the great interior lakes like Konya dried up, leaving behind alluvium with reeds and thickets where wild cattle could thrive; the land could be cleared by burning and yield excellent farm land; locations like this would have been ideal for a diverse economy of hunting, fishing, farming, and herding, such as existed at Çatalhöyük.

western half of the Konya Basin, may have dried up earlier than this, sometime between 15,000 and 10,500 BC.³⁰ The resulting character of the soils is summarized by de Meester:

All soils of the Basin have a high percentage of fine earth carbonates in common. This is mainly caused by the calcareous nature of the parent material, which is derived from the surrounding limestone uplands. Due to the semi-arid climate no part of the soil is richly decalcified, the pH is never less than 7. Secondary carbonate enrichment is common, causing the formation of calcic horizons at a depth of about 50 cm.³¹

These soil studies, although not carried out in order to research the plasters or mud brick at Çatalhöyük, provide useful information on the possible composition and material sources for the plasters and mud brick. Most of the soil around the site is made up of highly calcareous fine earth carbonates, originated from both the parent material and as microcrystalline calcite due to secondary enrichment of the soil. This naturally formed soil of calcareous fine earth carbonates could have been selected and manipulated to form earthen plasters of great strength.

2.4 Microscopical examination and analysis

2.4.1 Samples and bulk sample examination

Plaster samples were examined using several techniques in order to describe qualitatively and quantitatively their macrostructure and microfabric. Examination of the bulk samples provides important information about the basic composition of the plasters, the condition of the plasters before treatment, and technological considerations necessary to the analysis and treatment of the plasters.

³⁰ Neil Roberts, "Late Quarternary Geomorphological Change and the Origins of Agriculture in South Central Turkey," *Geoarchaeology* 6, no. 1 (1991): 9.

³¹ T. de Meester, *Highly Calcareous Lacustrine Soils in the Great Konya Basin, Turkey*, (Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation, 1971), 11.

The samples used to characterize the plasters at Çatalhöyük were removed from the site for analysis in 1994 by Wendy Matthews and in 1995 by Constance Silver and Frank Matero. Thirty-three samples were received by the Architectural Conservation Laboratory of the University of Pennsylvania. (Appendix B). These were taken from oven floors, room floors, and wall surfaces. Most of the samples are fragments of wall plaster, but there are some relief plasters as well. In some cases, samples contained the mud brick substrate on which the subsequent plaster layers were applied, but more often only the plaster layers were present in the sample. The samples ranged in surface area from less than 5 cm² to over 350 cm², with thicknesses generally between 5 cm and 10 cm. The total amount of intact plaster within a single sample fell between 5 cm³ and 1500 cm³.

The samples were first pre-sorted to determine which should be used for characterization, based on the number of plaster layers present, the presence of mud brick substrate, and the size and condition of the sample. The specific room location was not deemed necessary at this time, but the type of plaster, whether flat wall plaster, relief plaster, or floor plaster, was considered critical to the initial characterization studies. Probably none of the samples contained their full sequence of plaster layers, but the samples with the most layers probably retained most of the original stratigraphy. Thus, a large number of plaster layers was considered desirable in selecting samples for characterization. Because the relationship between the plaster layers and its mud brick substrate is an important consideration for treatment, samples which contained evidence of the substrate were selected for characterization. Finally, in order to minimize the number of variables in each type of analysis due to differences between samples, the larger samples were chosen for characterization because they would provide more

material for the different levels of analysis and in some cases could also be used for the consolidation testing program.

Four representative samples were chosen for characterization. These samples were labeled A, B, C, and D. Sample A is the largest of the samples and consists of many superimposed layers attached to a small amount of remaining mud brick. The sample was selected for analysis because it contains some of the mud brick substrate and because it is large with many plaster layers. Sample B is made up of curved plaster layers with two red painted layers, making it unique among the samples and thus of importance for characterization of a possible painted relief plaster. There are small amounts of mud brick attached to the sides of the sample. Sample C is similar to Sample A in appearance and also has a multitude of plaster layers, but is smaller in size. Sample D is mostly composed of mud brick and has several plaster layers attached to it. This sample was chosen for characterization because the mud brick appears to be of a different composition than what has survived with the other samples.

The four chosen samples were first analyzed as bulk samples under normal daylight with the unaided eye and under a low power magnification of 10x to 30x using a Nikon SMZ-U stereomicroscope and quartz halogen illumination in order to characterize the macrostructure, identify any distinguishing features, and evaluate deterioration. Optical properties such as the color of the plaster layers and substrate, the texture of the different components, and evidence of any inclusions were noted. In some cases, chemical reagents were used to characterize chemical properties.

Sample A is a fragment of wall plaster with alternating strata of light brown and white plaster layers. The light brown layers are generally thicker than the white layers and probably serve as a ground. The brown layers have a Munsell color equivalent of 2.5Y

8.5/2.³² White inclusions, perhaps fragments of the degraded underlying white layer or bits of marly soil, can be seen in this ground layer. The white layers are much more homogenous in texture and are probably a finish plaster. When viewed from above in raking light, parallel brush marks can be seen on the top of both the light brown and the white plaster layers, indicating that the plaster was applied by brushing. (Figure 8). Most of the layers appear to be fairly well attached to the adjacent layers, but there is some cracking parallel to the layers. Cracking perpendicular to the layers is less common but does occur. In addition to the ground and finish layers, there is a thicker preparatory coat attached to the wall plaster. This preparatory coat is the same color as the ground layers. There are impressions left from organic material in this preparatory layer and in some cases, surviving plant fibers. (Figure 9). The mud brick which survives on Sample A is a yellowish brown color (2/5YR 5/2). One drop of 6M hydrochloric acid (HCl) dropped on part of Sample A produced violent efflorescence and dissolved nearly the entire piece of plaster, indicating a high carbonate content typical of fired lime or marl soil plasters.

The relief plaster, Sample B, has a more uneven texture than the wall plaster samples. Almost no white layers are visible, but where they exist they are associated with the red paint layers (7.5R 4/6). Some dark brown material which may be mud brick is attached to the sample. The majority of the sample is a soft, powdery light brown packing plaster used to form the curved shape of the relief. The painted layers follow the contour of the sample.

³² The Munsell color number indicates the hue, value, and chroma of a substance. The hue, indicated by the 2.5YR notation, is where the color falls in the range of colors from purple to red. The value is how dark or light the color is and is marked by 8.5/ in this example. The chroma, /2 in this case, is the saturation of the color which ranges from 0, a neutral gray of the same value, to 8, a vivid, fully saturated color of the same value. All Munsell readings were determined by comparing the sample to a set of 199 color chips prepared by Munsell Color in natural daylight.

Sample C is similar to Sample A in structure and physical characteristics. The ground layers are light brown (2.5Y 8.5/2) and nearly parallel to each other and the white finish layers. The light brown preparatory coat (2.5Y 7/4) is loosely compacted and has many impressions left by organic material. There is some fibrous organic material still intact in the sample. The mud brick substrate attached to Sample C is yellowish brown (10YR 5/4).

Sample D is primarily composed of dark brown mud brick (10YR 5/2) which tends to crumble when handled. Black, brown, orange, and white particles as well as quartz fragments are visible in the mud brick. A preparatory coat 5 mm thick followed by 4 mm of plaster is attached to the mud brick. There is considerable delamination between the plaster layers.

The bulk samples appear to represent two types of plasters found at Çatalhöyük: wall plasters and relief plasters. Each of the wall plasters display similar characteristics. They have relatively even layers of alternating light brown and white plaster. The relief plaster is molded into a curved form, with painted layers around the edge of the curve. The preparatory coats of the wall plasters and the packing of the plaster of the relief plaster have fiber impressions and in some cases surviving organic material. In general, the mud brick substrate of each of the samples is very friable and contains fiber impressions.

2.4.2 Cross section examination

Following visual characterization of the bulk samples, cross sections were prepared in order to determine the stratigraphy of the plaster layers and identify the microstructure of the different layers. The cross sections were taken from the epoxy-

impregnated fragments of plaster remaining from thin section preparation. In this way, a cross section complementary to the thin section could be used. The samples were examined under a Nikon SMZ-U stereoscope at 4x to 75x magnification in normal reflected quartz halogen light to reveal the structure of the different plaster layers, characteristic components, and evidence of inclusions. (Appendix C).

Cross section A₁, taken from Sample A, has up to 154 layers of plaster which are nearly parallel near the top surface of the sample, but more distorted near the substrate. (Figure 10). Inclusions intrinsic to the ground plaster disrupt the adjacent finish layers and subsequent layers which are then distorted around the location of the inclusion. There is no evidence of soiling or soot between any of the plaster layers. However, unlike the other cross sections, Section A₁ possesses two layers which are a lighter brown than the ground layers. These two layers, in between a ground layer and a finish layer, may be a ground plaster manufactured with soil from a different source or at a different time of the year.

Several layers of plaster are visible in the cross section of the relief plaster sample, Section B₁. (Figure 11). These layers are all similar in color and texture to the plaster in the middle of the sample which is used as a packing plaster to form the rounded shape. The packing plaster has many vacuoles which tend to follow the contour of the curved shape. The subsequent plaster layers are identified by the accumulation of surface deposits in between layers and, less often, by slight changes in color. There are also paint layers and finish plaster layers. The two paint layers on the sample are dark red. They vary in thickness, even within the same layer. In some cases, the paint material has seeped through cracks in the ground plaster below it to the earlier paint layer indicating existing cracking at the time of painting. Associated with and underlying these paint

layers are thin white finish plaster layers. These layers are not consistent in thickness and do not completely encircle the curve of the relief.

Cross section C_1 , which is the most complete wall plaster sample, has 160 parallel layers of alternating finish and ground plaster on a preparatory coat and a small bit of mud brick. (Figure 12). The finish layers are consistently thinner than the ground layers, averaging from 0.025 mm to 0.100 mm and from 0.100 to 0.400 mm respectively. The finish layers are white and the ground layers are light brown. The preparatory layer is of the same composition as the ground layers, but is thicker, being about 1 mm to 3 mm, and has more long, thin voids which tend to run in the same direction as the plaster layers. Some of these vacuoles contain plant fibers of an undetermined type. There is no accumulation of dirt or soot in between any of the plaster layers indicating a short time period before replastering or diligent cleaning of the surfaces before replastering. Cracks tend to occur in the finish layer, usually near the top surface of the stratigraphy. If the finish layers are made from a more clayey material with less aggregate than the ground layers it is possible that they would experience more cracking upon initial drying. It is also likely that the layers closer to the top of the stratigraphy were subjected to a greater amount of environmental stress, both when exposed during initial occupation of the site, when covered by earth pressing against the plaster, and when exposed to the hot dry air upon excavation.

Cross section D_1 consists of a mud brick substrate divided into two zones, a preparatory coat, and several plaster layers. (Figure 13). The two zones of the mud brick are differentiated by the size and density of the large mineral fragments within the fine matrix. The preparatory coat is similar in thickness and color as the preparatory plasters of the other cross sections. The plaster layers are nearly parallel to the surface of the

preparatory coat. There is a greater number of ground layers than finish layers, with some of the ground layers separated from each other by thin dirt layers.

In summary, characterization of cross sections shows that at least two different types of plaster were used at Çatalhöyük. Wall surfaces appear to have been replastered regularly and frequently. Often, the white finish plaster served as the only surface decoration: no evidence of plain or complex mural painting was found on these samples. Based on a single sample, the plaster reliefs appear to have been made using only one type of plaster which was then decorated and redecorated with paint. Characteristics of the two types of plasters such as color and layer thickness appear to be fairly consistent over a period of many years, indicating little change in material source and manufacturing technology.

2.4.3 Thin section examination

The use of thin section petrography has been advanced as an effective analytical tool in the study of ancient plasters. The technique, originally developed for the examination of rocks and minerals and later used in soil studies, allows micromorphological characterization of archaeological artifacts and features. By observing a thin section under transmitted polarized light, the mineralogical composition and relationship between component materials, or microfabric, can be determined. Information concerning grain size, mineral impurities, and textural characteristics can be used to evaluate the production and application of plasters. Because thin section analysis reveals not only composition, but also the structure of the components and the interrelationships between them, it is often more useful in the study of plasters than other

analytical techniques such as x-ray diffraction, scanning electron microscopy, and elemental analysis.³³ (Appendix C).

A representative fragment of each of the four bulk samples was sent to a commercial petrographic laboratory for thin section preparation.³⁴ The thin sections were prepared by the following procedure:

preparation for impregnation:

- samples dry cut (without lubricant) with large diamond-edge blade to the size of a glass slide
- placed in rectangular plastic molds
- put in a dehydrator for a day (140-150° C) to drive water out and facilitate impregnation

impregnation:

- low viscosity epoxy resin poured into sample in a vacuum chamber to fill pores
- put in an oven overnight (150° C) to cure

surfacing:

- rock surface on sample exposed and ground flat using flat diamond discs lubricated with kerosene to make it fit flat on a glass slide
- put in dehydrator to dry off oil residue

mounting:

- glass slide glued onto sample

³³ Chandra L. Reedy, "Thin-Section Petrography in Studies of Cultural Materials," *Journal of the American Institute for Conservation* 33, no. 2 (Summer 1994): 123-124.

³⁴ The thin sections were prepared by Spectrum Petrographics, Inc., 499 Dillard Gardens Road, Suite 2, Winston, OR 97496, United States, 800/625-2476 (telephone).

cut-off:

- diamond-blade saw (with vacuum chuck to hold slide to chuck under pressure)
used to cut off a thin section from the impregnated sample

grinding:

- section ground to 30 microns using a flat diamond-edge saw, checking under a microscope during grinding

staining:

- section etched by holding thin section over vapor of hydrofluoric acid
- sample placed in beaker of alizarin red S to stain for calcite and sodium cobaltnitrate to stain for potassium feldspar

cover glass:

- several drops of UV-curing epoxy put on sample
- cover glass placed on sample and allowed to cure under UV light

Three large thin sections and one standard size section were prepared. The larger sections, made from a wall plaster, a relief plaster, and a sample predominantly consisting of mud brick with some plaster, were required in order to get a more complete stratigraphy of the samples. The standard thin section was of a wall plaster

Thin section A₂, a standard size section (27 x 46 mm), and large thin sections (51 x 75 mm) labeled B₂, C₂, and D₂ and prepared from samples B, C and D respectively were used in the characterization and analysis of the plasters from Çatalhöyük. All of the thin sections were stained with both alizarin red S and sodium cobaltnitrate. The thin sections were examined in plain and crossed transmitted polarized light using a Zeiss

MC100 Axioplot Polarizing Microscope and a Nikon Optiphot 2-Pol Polarizing Microscope at 25x to 400x magnification.³⁵

Micromorphological analysis of thin section A₂, a wall plaster, reveals that there are two distinct types of plaster based on the way that they take up the different stains, the inclusions in each layer, the density or compactness of material, and the thickness of the layer. The finish layers are usually homogeneously textured with even surfaces, few inclusions, and thicknesses typically ranging from 0.025 mm to 0.100 mm. They are more compacted than the ground layers which are usually from 0.100 mm to 0.400 mm and have more mineral fragments, mostly quartz and feldspar. These mineral fragments can be classified according to their size as either medium-sized particles or coarse-sized particles.³⁶ The medium-sized particles correspond to the fine sands, which range from 0.020 mm to 0.075 mm, and the coarse-sized particles related to the coarse sand, which has a diameter between 0.075 mm and 4.75 mm. Overall, the plaster layers do not have more than 2% medium- and coarse-sized particles. The fine matrix is the predominant feature in the plaster layers and is most likely calcite. This material stains positive for calcite, although in uneven concentrations. The preparatory layer appears to be the same material as the ground layer but has more voids; it is from 1 mm to 3 mm thick. The preparatory layer of section A₂ has a large charcoal fragment which has been mineralized around its edges. There are also fragments of material which stain deep red with alizarin red S, suggesting that they contain a high amount of calcium carbonate. Their shape and

³⁵ Professor Gomaa Omar of the Department of Geology, University of Pennsylvania graciously provided endless time, expertise, and advice in thin section examination.

³⁶ This classification is based on ASTM D 422: Standard Test Method for Particle-Size Analysis of Soils," (Philadelphia: ASTM, 1993) and "D 653: Standard Terminology Relating to Soil, Rock, and Contained Fluids," (Philadelphia: ASTM, 1993).

surface texture appear similar to shell, indicating that the source of the plaster is the former lake bed in which Çatalhöyük sits and that the plasters are not made of fired lime.

Plaster layers in the relief plaster sample, thin section B₂, are difficult to identify in thin section. The bulk of the sample is made up of loosely compacted material with up to 5% medium- and coarse-sized inclusions. The shell-like fragments that appear in the preparatory layers of the wall plasters are also in the packing plaster of the reliefs. The painted layers appears as uneven dark red layers running around the sample. Associated with the paint layers are fractured crystals which were initially thought to be quartz but after later analysis with scanning electron microscopy and energy dispersive spectroscopy proved to be gypsum. They are most often positioned within the paint layer and may be gypsum crystals which subsequently formed when sulfates present in the paint material reacted with calcium in the plaster above and below the paint layers.

The structure and composition of thin section C₂ is similar to sample A₂ except that there are fewer coarse-sized particles and there are more voids in the ground layers. In addition, the finish layers of thin section C₂ become more deeply yellow when stained with sodium cobaltnitrate than the finish layers of A₂.

The two zones of the mud brick substrate of sample D are clearly identifiable in the thin section D₂. A great variety of minerals, including shell fragments, are present in each zone of the mud brick, but quartz and feldspar are the principle components. The preparatory coat is similar to the preparatory coats of sections A₂ and C₂, but the plaster layers appear different in thin section. The dirt layers separating the plaster layers are not visible in the thin section, so the ground layers appear thicker than they actually are.

The presence of unburned shell fragments indicates that it is likely that the plasters can be classified as earthen plasters, rather than lime or gypsum, made from soils which

have been manipulated but not fired. Firing at temperatures necessary to make lime plasters would have altered the shell fragments beyond recognition. The greater percentage of medium- and coarse-sized particles in the ground layers and the fine calcite matrix indicate that the materials used in the plasters were carefully selected and probably processed to obtain the desired qualities of a thin, even finish plaster on top of a strong, thick ground plaster. The absence of large particles in the finish layers may indicate sieving, levigation, or other substantial manipulation of the soils used for plastering wall surfaces.

2.4.4 Scanning electron microscopy with energy dispersive spectroscopy

Scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) provides a level of description and analysis not available in the examination of cross sections and thin sections using optical microscopy. The morphology and distribution patterns of the constituents are observed within each layer and as a function of three-dimensional structure with much more definition than is available using optical light microscopy. In addition, EDS analysis gives the relative quantity of the components based on their elemental makeup. (Appendix D).

The same four cross sections that were examined under optical microscopes were analyzed using a JEOL 6400 scanning electron microscope to provide a more complete assessment of the component materials and their arrangement.³⁷ They were polished using 240, 400, 600, and 1200 grade sandpaper, then coated with carbon to provide a conductive surface. Each sample was viewed at various magnifications and energy

³⁷ SEM examination was performed in the Laboratory for Research on the Structure of Matter, University of Pennsylvania with the invaluable assistance of Rollin Lakis and Xue-Qin Wang.

dispersive spectra were obtained. In addition, x-ray dot maps showing the location of particular elements within a sample were obtained for some areas.

Scanning electron microscopy indicates that the distribution of component materials within a single layer varies depending on the role of the layer (whether it is a ground layer or a finish layer) but remains constant over time within a sample. The material in the finish layers is more compacted than the material in the ground layers. Within each layer there are no detectable changes in morphology indicative of burnishing, scraping, or other surface treatment. There are also no substantial changes in morphology or composition between the earliest applied layers and the latest layers within a sample.

Scanning electron microscopy with energy dispersive spectroscopy reveals three basic types of plaster based on elemental composition. The finish plasters of the different samples appear to be identical when examined using visual light microscopy but when studied using SEM and EDS they are actually of two types. Only one type of finish plaster occurs in each sample, but between samples there are clearly two types of finish plaster. One type is rich in magnesium whereas the other type does not contain significant amounts of that element. The energy dispersive spectra for the second type of finish layer are similar to the spectra of the ground layers, although the ground layers contain more silicon than the finish layer. Both contain calcium, silicon, potassium, aluminum, magnesium, chlorine, and sometimes iron, usually in this order of abundance. The preparatory layer and the packing plaster of the relief plaster are identical to the ground layers based on elemental composition. The primary elements are calcium, silicon, potassium, aluminum, magnesium, chlorine, and sometimes iron. Thus there are two types of finish plasters present in the samples examined and another type of plaster used as a packing, preparatory, and ground material. The identifying composition of each

layer type remains constant across a sample indicating the selection of similar materials over the time (perhaps many years) between the initial plastering and the last plastering.

There appears to be one type of soil used for the packing plaster, preparatory coat, and ground layers of the relief and wall plasters. This material is rich in calcium with aluminium, silicon, chlorine, potassium, and iron present in sizable quantities. With the exception of the high calcium content, the spectrum for this plaster has the same elements in similar relative quantities as the reference spectra for the clay smectite.³⁸ It would appear that smectite is a dominant clay species and that the soil used to manufacture this type of plaster is a marl composed of calcareous material and smectite clays. A marl is an earth deposit made up of an intimate mixture of clay and calcium carbonate found under marine or lacustrine conditions and containing 35% to 65% clays and 65% to 35% calcium carbonate.³⁹

The origin and clay mineralogy of the two types of finish plaster is less clear. The two types of finish plaster may represent two types of marl or soft lime soils differentiated by the nature of the principle clay. One type contains a clay with a great deal of magnesium and the other is similar to the ground plaster soil. Magnesium is found in chlorite clays. The spectra for the finish layers containing magnesium are similar, although not identical to reference spectra for chlorite, and may indicate that this clay is the source of magnesium.⁴⁰ Alternately, an identical or similar soil may have been used for each type of finish plaster but the clays in the soil may have been altered at

³⁸ Joann E. Welton, *SEM Petrology Atlas* (Tulsa, OK: The American Association of Petroleum Geologists, 1984), 72-82.

³⁹ Robert L. Bates and Julia A. Jackson, eds., *Glossary of Geology*, 3rd ed. (Alexandria: American Geological Institute, 1987), 403.

⁴⁰ Joann E. Welton, *SEM Petrology Atlas* (Tulsa, OK: The American Association of Petroleum Geologists, 1984), 38-49.

some point. Magnesium ions may take the place of aluminium ions in illite clays.⁴¹ Except for the quantity of magnesium, spectra for the magnesium-rich finish plaster is nearly identical to spectra of the finish plaster which does not contain magnesium. This may indicate that the difference in elemental composition is due to the exchange of ions rather than the use of a soil with a completely different clay. Another possibility is that there is a sizable percentage of both smectite and illite clay minerals in the plasters or the clays may be mixed layer clays. Smectite can transform into illite under hydrothermal environments, with interstratified illite/smectite minerals being a characteristic marker of this transformation.⁴²

The red paint layer is made up of primarily iron and oxygen, suggesting that it is mainly an iron oxide. In some areas, the paint appears to be mixed with plaster similar in composition to the ground plaster. The use of a finish plaster before application of the paint layer and the presence of gypsum crystals near the paint layer were confirmed using SEM and EDS.

Inclusions within plaster layers were also examined using SEM and EDS. The elemental composition of characteristic features was determined to confirm conclusions based on examination of the thin sections. Typical inclusions are subangular aggregates composed almost entirely of silicon and oxygen (quartz), subround and subangular calcareous particles (calcite and shell fragments), subround particles with silicon, aluminium, iron, and a relatively high percentage of potassium (potassium feldspar), and

⁴¹ Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide*, translated by Albert Gompers and Janice Schilderman (London: Intermediate Technology Publications, 1994), 27.

⁴² A. Inoue, "Formation of Clay Minerals in Hydrothermal Environments," chapter 7 in *Origin and Mineralogy of Clays: Clay and the Environment*, edited by Bruce Velde, 268-329 (Berlin: Springer-Verlag, 1995).

subround and rounded blebs with compositions similar to the ground plaster layers (agglomerated clays).

2.5 Chemical analysis

2.5.1 Wet chemical analysis

The plasters and mud brick from Çatalhöyük were further characterized using classical wet chemical methods. Because of the earthen nature of the plasters, tests developed for soil and earthen building materials were used. The content of organic material, soluble salts, and acid-soluble material in plaster fragments and the granulometry and pH of the plasters were determined. These tests give important information about the physico-chemical properties of the plasters and their mud brick substrate and are thus critical to evaluating the success of consolidation as a treatment.

2.5.1.1 Organic material content

Solid organic material is often used in the manufacture of earthen plasters as additives which increase strength and reduce shrinkage. Most often, locally available material such as animal hair or vegetable fibers are used. These are added into the plastic mixture and remain in the plaster upon drying. Humification, the degradation of organic material and its gradual mineralization, usually occurs and makes the quantifiable determination of the original organic content difficult.⁴³

The humified organic material content of the plasters and mud brick was determined using a qualitative test suggested by CRATerre for the assessment of the

⁴³ Marie Agnus Courty, Paul Goldberg, and Richard Macphail, *Soils and Micromorphology in Archaeology* (Cambridge: Cambridge University Press, 1989), 146-147.

presence of organic material.⁴⁴ Approximately 30 grams of plaster material were stirred in 100 milliliters of a 3% (w/v) solution of sodium hydroxide (NaOH). The soil in the mixture was allowed to settle over a period of 24 hours and the color of the liquid portion was observed. A light color liquid indicates a low organic matter content, while a dark brown or black color means a high organic material content. The results of the analysis are given below:

Organic Material Content		
Sample	Color	Conclusions
Wall plaster 1 (Sample A)	Light mustard yellow (5Y 8/12)	Low organic content, probably due to fiber additives in the preparatory layer
Wall plaster 2 (Sample C)	Golden yellow (5Y 8/8)	Low organic content, probably due to fiber additives in the preparatory layer
Relief plaster (Sample B)	Golden yellow (5Y 8/10)	Low organic material content
Mud brick (Sample D)	Rust brown (10 R 4/6)	High organic material content due to use of fibers as additive to the mud brick

Table 1

2.5.1.2 Soluble salt content

The determination of soluble salt content is important in the characterization of plasters, mud brick, and other materials because salts play a critical role in the deterioration and treatment of architectural materials. Both a qualitative and semi-

⁴⁴ Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide*, translated by Albert Gompers and Janice Schilderman (London: Intermediate Technology Publications, 1994), 66.

quantitative analysis of soluble salt content was made on the plasters and mud brick from Çatalhöyük.

An oven dried sample was soaked in deionized water for 24 hours and then filtered. Microchemical tests were performed on the filtrate to determine the presence of chlorides (Cl^-), nitrates (NO_3^-), phosphates (PO_4^{3-}), and sulfates (SO_4^{2-}). The reagents used are 0.1 M silver nitrate (AgNO_3) to identify chlorides and phosphates, 0.25 M lead acetate ($\text{Pb}(\text{CH}_3\text{COO})_2$) as a confirmation for chlorides and sulfates, 0.25 M barium chloride (BaCl) to find sulfates and confirm phosphates, iron-II-sulfate crystals (FeSO_4) and concentrated sulfuric acid (H_2SO_4) which react with nitrates, and diphenylamine reagent (solution in H_2SO_4) as a confirmation for nitrates. Each positive indication must be confirmed using another reagent and every negative was confirmed by testing the reagent in deionized water and a control solution. The control solutions were sodium chloride (NaCl), sodium nitrate (NaNO_3), sodium phosphate (Na_2HPO_4), and ammonium sulfate ($(\text{NH}_3)_2\text{SO}_4$). The following tests were performed:

Soluble Salt Content: Reactions		
Anion	Primary Test	Confirmation Test
Chloride	5 ml of test solution placed in test tube 1-2 drops of 0.1 M silver nitrate added Bluish-white gelatinous precipitate indicates positive	5 ml of test sln placed in test tube 3 drops of 0.25 M lead acetate added White ppt indicates positive
Nitrate	Several crystals of iron-II-sulfate placed in a spot plate 2-3 drops of test sln added to crystals A few drops of concentrated sulfuric acid added to edge of sln Brown color near crystals indicates positive	1 ml of test sln placed in test tube 1 drops of diphenylamine reagent added Blue color indicates positive
Phosphate	5 ml of test sln placed in test tube 1-2 drops of 0.1 M silver nitrate added Pale yellow ppt indicates positive	5 ml of test sln placed in test tube 1-2 drops of 0.25 M barium chloride added White, finely-clumped ppt indicates positive
Sulfate	5 ml of test sln placed in test tube 1-2 drops of 0.25 M barium chloride added White ppt indicates positive	5 ml of test sln placed in test tube 3 drops of 0.25 M lead acetate added White ppt indicates positive

Table 2

Five samples representing the four materials tested for organic material content and an additional piece of relief plaster were analyzed: two wall plaster fragments, two relief plaster samples, and a bit of mud brick. The results of the qualitative analysis are given below:

Soluble Salt Content: Qualitative Results				
Sample	Chlorides	Nitrates	Phosphates	Sulfates
Wall plaster 1 (Sample A)	weak positive	positive	negative	positive
Wall plaster 2 (Sample C)	weak positive	positive	negative	positive
Relief plaster 1 (Sample B)	weak positive	positive	positive	positive
Relief plaster 2	weak positive	positive	positive	positive
Mud brick (Sample D)	weak positive	negative	positive	positive

Table 3

The qualitative analysis indicates that salts of sulfates and nitrates are the primary concern. The sulfates may be gypsum, which was found to be present in at least one relief plaster sample using SEM with EDS. Phosphates appear to be associated with the relief plasters and mud brick more than the wall plasters. Chlorides are present in very weak concentrations.

Interpretations of the results are preliminary at best. A possible source of the nitrates found in the plasters are the decomposed human remains which were buried under the room floors. The absence of nitrates in the mud brick sample tested may be due to the original location of the sample. Sulfates are the most prevalent type of soluble

salt. The elemental composition found to exist using energy dispersive spectroscopy does not include a meaningful amount of sulfur. Thus, it is unlikely that sulfates are intrinsic to the soils used to manufacture the plasters. They must then be contaminants, either from other materials, such as the paint material in the case of the painted plaster, or from the combustion products of sulfur-containing materials. The soil which buried the site prior to excavation may have been different compositionally than the soils originally used as the source of building materials. Contaminants in this burial soil may be the source of some of the soluble salts.

A semi-quantitative analysis of soluble salts present in the plasters and mud brick was performed. This is based on the difference between the weight of the oven-dried sample before soaking with deionized water and the weight after drying the filtered material. It is assumed that most of the salts will be solublized by the deionized water and flushed from the sample. The results are given in the following chart:

Soluble Salt Content: Quantitative Results			
Sample	Mass ₁ (grams)	Mass ₂ (grams)	Percent Soluble Salts
Wall plaster 1 (Sample A)	24.47	24.14	1.3%
Wall plaster 2 (Sample C)	22.90	21.68	5.3%
Relief plaster 1 (Sample B)	4.79	4.80	0%
Relief plaster 2	31.97	31.63	1.1%
Mud brick (Sample D)	21.29	21.10	0.89%

Table 4

Quantitative analysis of the soluble salt content of the plasters from Çatalhöyük indicates that the amount of salts present is generally near 1% by weight in the wall plasters, relief plasters, and mud brick. The two results anomalous to this may be due to unrepresentative sampling or experimental procedural error. In any case, further analysis is needed to determine more accurately the soluble salt content.

2.5.1.3 Acid-soluble content

Analysis of the acid-soluble content of plasters is critical to understanding the nature of the plasters and their relative proportions of binder and aggregate. The majority of the acid-soluble material in plasters is calcium carbonate, most often attributed to a lime or calcareous clay binder. A simple procedure used to determine the acid-soluble

content is to digest a pre-weighed sample with 15% (v/v) hydrochloric acid (HCl).⁴⁵ The material lost during the process as carbon dioxide is equivalent to the carbonate fraction, assumed to be calcium carbonate, and is determined by measuring the difference in the mass of the sample before acid-washing and after acid-washing. The following results were obtained, testing the same material that was used in the soluble salt analysis:

Acid-Soluble Content: Results					
Sample			Mass ₁ (grams)	Mass ₂ (grams)	Percent Carbonates
Wall plaster	1	(Sample A)	25.16	11.80	53.10%
Wall plaster	2	(Sample C)	24.93	9.97	60.05%
Relief plaster	1	(Sample B)	3.69	1.77	52.03%
Relief plaster 2			33.32	16.00	51.98%
Mud brick		(Sample D)	21.57	18.54	14.05%

Table 5

As expected, the plasters contain a great deal of acid-soluble material identified as carbonates as compared to the mud brick. In general, the relief plasters contain nearly as much calcareous material as the wall plasters, owing to the similarity of plaster

⁴⁵ Jeanne Marie Teutonico, *A Laboratory Manual for Architectural Conservators* (Rome: ICCROM, 1988), 112-115.

composition. Most of the solublized material in the mud brick, as well as some in the plasters, is probably calcareous aggregate, rather than binder.

The material that was not dissolved by the 15% solution of HCl was observed using a Nikon stereoscope at 30x magnification under normal reflected light. The non-soluble content of both wall plaster samples is composed almost entirely of equal sized light brown particles (2.5Y 8/4) which tend to clump together. There is almost no quartz, mica, or other large mineral fragments. The non-soluble material of the relief plasters is almost entirely made up of light beige particles (2.5Y 8/2). There are some orange, red, and black particles, including burned organic material, and some quartz and mica, these distinct minerals do not make up more than 2% (by volume) of the entire sample. The non-soluble residue left from digesting the mud brick with acid is over 25% (by volume) subangular quartz particles. There are lesser amounts of mica, subangular white and orange fragments, yellow and orange particles, and light brown fine material. There are also some black inclusions, some of which is charcoal.

2.5.1.4 Granulometry

Sieving and wet gravimetric analysis was performed in order to determine the relative particle sizes present in the wall and relief plasters.⁴⁶ Knowing the degree of particle size variation is critical to understanding important aspects of plaster manufacture and the material characteristics of the plaster. Two ten-gram samples, a wall plaster and a relief plaster, were first dry sieved and the fine material passing through a 75 μm sieve was further characterized. The fine material was examined at 30x magnification and the relative particle size determined by wet gravimetric analysis.

⁴⁶ Ibid., 73-95.

The results of the dry sieving are given in the following table:

Particle Size Distribution: Dry Sieving Results				
Wall Plaster			Relief Plaster	
Initial Mass:	101.37 grams		Initial Mass:	102.49 grams
Mass retained (g)	Percent passing	Sieve diameter (mm)	Mass retained (g)	Percent passing
0.14	99.86 %	2 . 3 6	0	100 %
0.13	99.73	1 . 1 8	0.05	99.95
0.32	99.41	0 . 6 0 0	0.10	99.85
0.83	98.59	0 . 3 0 0	0.80	99.07
2.28	96.34	0 . 1 5 0	3.52	95.64
4.35	92.05	0 . 0 7 5	4.71	91.04
2.10	—	p a n	0.54	—

Table 6

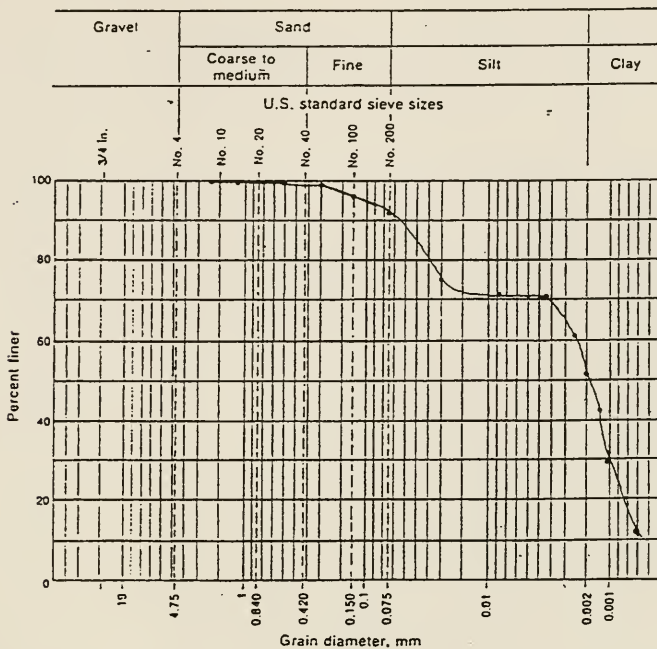


Figure 8: Particle size distribution of a wall plaster (Sample C). The wall plaster is predominantly composed of silts and clays with very little sand-size particles.

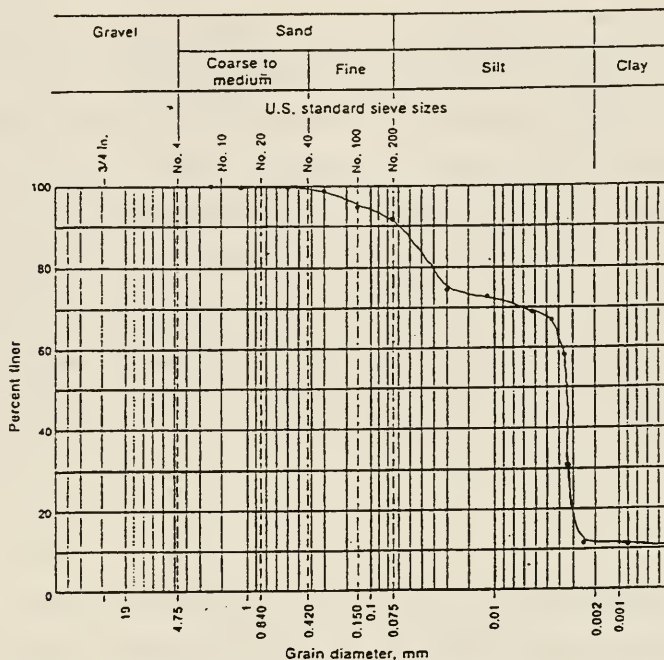


Figure 9: Particle size distribution of a relief plaster (Sample B). The relief plaster has relatively few sand-size particles, like the wall plaster sample, but has fewer clay-size particles than the wall plaster.

In both the wall plaster and relief plaster samples, almost all of the component particles are fine sands or smaller, with roughly 90% of the plaster being silts and clays, as determined by dry sieving. Wet gravimetric analysis indicates that the proportions of silts to clays in the two types of plasters differs significantly, however. Most of the very fine material in the relief plaster are silt-size particles. Only approximately 10% of the sample consists of clays. On the other hand, almost 50% of the particles making up the wall plasters are clays, with 30% being silts.

The difference in characteristic particle size between the wall and relief plasters is reflected in the visual variation between the material recovered by the pan during the dry sieving of each plaster type. When viewed at 30x magnification, the wall plaster particles passing the 75 μm are uniform in color and shape. They are almost all subangular beige particles which tend to clump together. There is some feldspar, but very little. The material passing into the pan during the sieving of the relief plaster has a much greater variation, with white particles being almost equal in number to the beige material and both subround and subangular shaped silts and clays. Orange and black particles are also visible, with some of the black material being organic. Quartz and feldspar are both present.

2.5.1.5 pH

The pH of the plasters and mud brick was found using colorpHast 5.0-10.0 indicator strips. The pH of the filtrate from the soluble salt analysis was used for this simple test. The following pH measures were recorded:

Wall plaster 1 (Sample A): 7.0

Wall plaster 2 (Sample C): 8.0

Relief plaster 1 (Sample B): 8.0

Relief plaster 2: 7.0

Mud brick (Sample D): 8.0

The results of the pH testing are consistent with soil reports from the area which indicate that the soils are generally basic, never having a pH below 7.

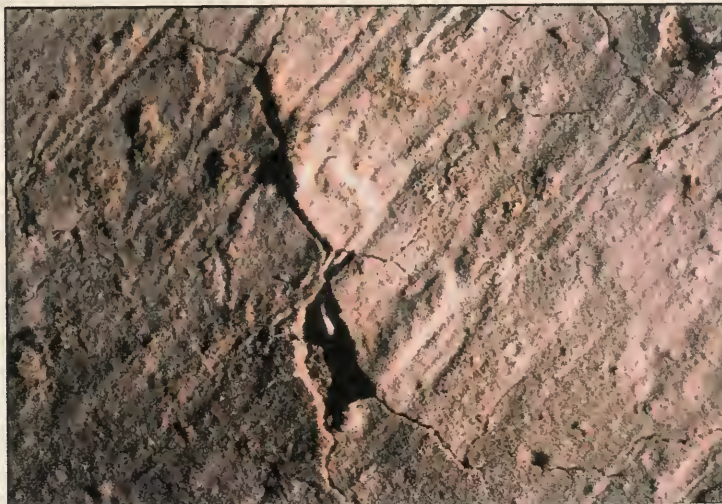


Figure 10: Photomicrograph of Sample A showing brush marks at 25x magnification under quartz halogen illumination. The brush marks run diagonally across the photomicrograph.



Figure 11: Photomicrograph of Sample A showing fiber impressions at 25x magnification under quartz halogen illumination.

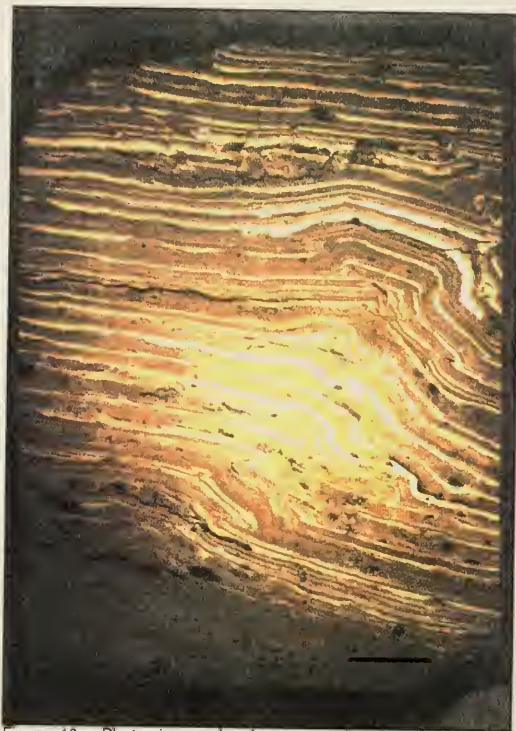


Figure 12: Photomicrograph of cross section A₁ showing full stratigraphy at 5x magnification under quartz halogen illumination. The bar equals 0.5 cm.

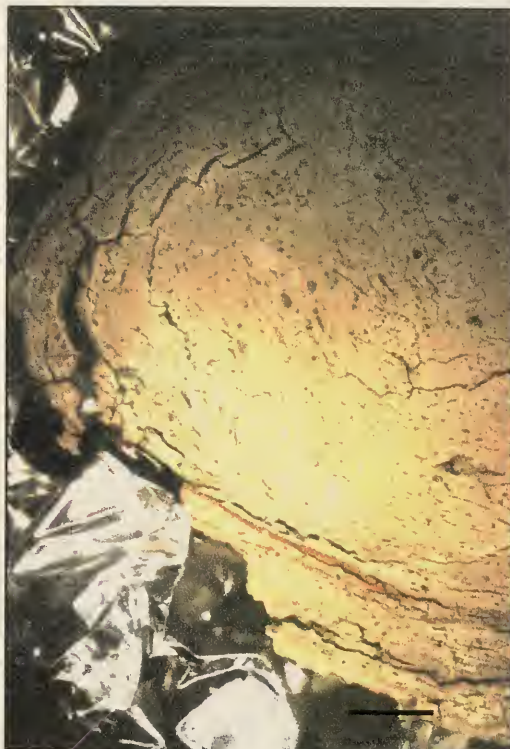


Figure 13: Photomicrograph of cross section B₁ showing full stratigraphy at 5x magnification under quartz halogen illumination. The bar equals 0.5 cm.



Figure 14: Photomicrograph of cross section C₁ showing full stratigraphy at 5x magnification under quartz halogen illumination. The bar equals 0.5 cm.

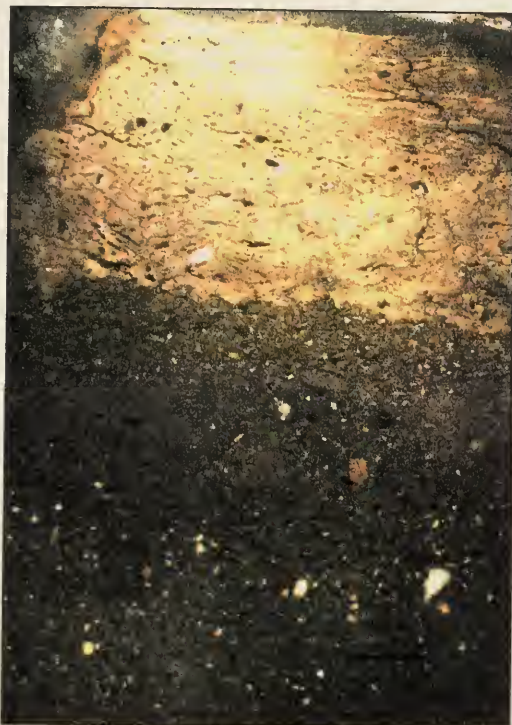


Figure 15: Photomicrograph of cross section D₁ showing full stratigraphy at 5x magnification under quartz halogen illumination. The bar equals 0.5 cm.

Chapter Three: Discussion of Objectives, Materials, and Methods of Plaster Consolidation

Consolidation is an intervention intended to slow down the rate of deterioration of a porous material exposed to weathering agents usually achieved through the deposition of a liquid substance which restores or improves the cohesive strength between component particles. The effectiveness of any particular consolidant is usually determined by how well it meets certain criteria which are evaluated using performance tests. Each class of consolidant has its advantages and disadvantages which must be considered when deciding upon a final treatment.

Although most consolidation research has focused on stone, the consolidation of plaster is becoming increasingly important as the perceived value of plaster as a contributing architectural element changes. Because plaster is chemically similar to some types of stone, many of the same materials that have been used successfully for stone consolidation have also been used for the consolidation of plaster. These are often synthetic materials, either organic or inorganic, which act as a binder between poorly bonded particles.

3.1 Performance criteria for consolidants

The purpose of consolidation is to restore the cohesive strength to friable or powdering materials such as plaster, adobe, paint, or stone.¹ This is achieved by the deposition of a new material into the pore system of the material to be consolidated. The consolidant acts as a binder, holding together the loose, separated particles or grains of the original material and sometimes adhering it to sound material. The consolidant is usually deposited as part of a deep-penetrating liquid system.

The effectiveness of a consolidation treatment can be evaluated based on a number of performance criteria. These performance criteria can be applied to any consolidant as a general framework. The choice of consolidant will depend on the specific issues of the application.

reestablishment of intergranular cohesion: The primary function of a consolidant is to restore intergranular cohesion. Often called consolidating value, this is usually assessed as a measure of the change in mechanical properties of the material. Strength tests and hardness tests can be used to evaluate the degree to which loose particles in a material have been consolidated. Consolidating value is dependent upon the compatibility of the consolidating system with the material, the mechanical and physical properties of the material, and the method of application.

depth of penetration and distribution of consolidant: A consolidant should have sufficient depth of penetration and uniform distribution to avoid the formation of zones of weakness between consolidated material and unconsolidated material. There is disagreement among conservators concerning depth of penetration.² One side argues that

¹ Frank Matero, "A Programme for the Conservation of Architectural Plasters in Earthen Ruins in the American Southwest: Fort Union National Monument, New Mexico, USA," *Conservation and Management of Archaeological Sites* 1, no. 1 (1995): 23.

² Pamela French, "The Problems of In Situ Conservation of Mudbrick and Mud Plaster," in *In Situ*

a light, superficial application of consolidant which yields a sacrificial consolidated zone is more appropriate in some cases. Presumably, sound material will lie below the deteriorated surface material so that forces such as salts and water which get behind the consolidated zone will only damage a small crust rather than a large portion of original material. The opposite view is that as deep a penetration as is possible should be sought, especially in cases where the surface of the material contains paintings or important reliefs.

Depth of penetration and distribution of a consolidant can be determined using microscopy and or reactive agents that stain the treated material. The degree of penetration is related to the molecular size, surface tension, viscosity, rate of evaporation, and curing rate of the consolidating system, the porosity, pore size distribution, and moisture content of the material to be consolidated, and the method of application. Smaller consolidant molecules will be able to penetrate the pore structure of a material more effectively. Viscosity and rate of evaporation can be adjusted by changing the solvent in which the consolidant is carried or by changing the solution percentage. Environmental conditions surrounding the object being consolidated can be controlled to affect depth of penetration, but while practical for small artifacts, it is not feasible for large-scale architectural features. A high internal moisture content in a material may interfere with penetration and distribution of the consolidant. In general, spraying gives the least penetration, while brushing yields better penetration, and total or partial immersion or prolonged contact through wicking usually assures the best results.³

Archeological Conservation: Proceedings of Meetings April 6-13, 1986, edited by Miguel Angel Corzo, (Los Angeles: The Getty Conservation Institute, 1987), 79-81.

³ P. Rossi-Doria, M. Tabasso, and G. Torracco, "Note on Conservation Treatments of Stone Objects," Section 6.12 in *The International Symposium on the Deterioration and Protection of Stone Monuments* (Paris: RILEM, 1978), 8.

compatibility of consolidant with material: A consolidant should be compatible with the material to be treated in chemical, structural, and thermal properties and should not produce residual byproducts that are harmful to the material.⁴ Consolidants which bond chemically with the material will yield greater cohesion and strength than consolidants which only fill the spaces between loose grains. The structure of the cured consolidant is also important, since introduced material which increase tensile strength may subsequently damage the original material. If the coefficient of thermal expansion and contraction of a consolidant is drastically different from that of the material to be treated, excessive forces between treated and untreated areas may cause harm unacceptable harm. The formation of salts or other chemicals as byproducts of the reaction between a consolidant and material may also cause damage. Compatibility can be assessed using strength tests, comparing treated to untreated material.

effect of consolidation on water permeability: Ideally, a consolidant should not affect the pore structure of the material or reduce hydrophobicity. The consolidant should allow water vapor transmission so that moisture and soluble salts will not accumulate behind treated material. Because water is the principle agent of deterioration for most architectural materials, decreasing hydrophobicity is likely to increase the rate of decay. The effects of consolidation on water permeability can be determined by comparing pore size distribution of treated and untreated material, and exposing the material to water in the form of water vapor, wet/dry cycles, constant droplets.

mechanical durability: The use of a consolidant should not increase the rate of erosion of a material. Durability will partly depend on the compatibility between the two

⁴ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 27-28.

components and will also depend on the effects of consolidation on water permeability. Another cause of consolidant failure is due to the degradation of the consolidant itself. Tests which simulate deterioration factors, such as salt crystallization, freeze/thaw cycles, and biological growth can be used to evaluate durability.

optical effects of consolidation: A consolidant should not alter the physical appearance of a material either upon initial curing or after weathering. Aesthetic alterations can be qualitatively and quantitatively determined using standard color matching systems or electronic chromometers.

reversibility/retreatability: Ideally, all conservation treatments are reversible. Since, in practice, very few treatments can actually be undone with no alterations to the material, other criteria such as retreatability become more important. Retreatability implies that either the same treatment or a different treatment can be carried out later on a consolidated material. It depends on the chemical nature of the consolidating system and the reaction between the consolidant and the material. Because most consolidants are deposited into a material as part of a liquid system which relies on a solvent for deep penetration, the reapplication of the solvent will permit retreatment theoretically. If a reaction has occurred which changes the chemical composition of the consolidant, retreatment may be more difficult.

ease and safety of application: Difficulty in application and toxicity of consolidating system are considerations which affect the choice of treatment. These factors are especially relevant to determining which consolidants can be used in large-scale application in the field, where less than ideal conditions should always be expected. Special application procedures such as covering a material during the curing period of the consolidant may be impractical in the field. Many of the solvents used in consolidation

systems are hydrocarbons which require special attention during preparation, application, and disposal.

There is no consolidant that completely satisfies all of the above performance criteria. However, some properties may be more important to the conservation of a material than others. Thus the expectations of a consolidating substance are another important factor in deciding its effectiveness. There are a number of products available to the conservator. The selection of any particular consolidant will depend on how it satisfies the performance criteria and considerations which are most important to the conservation goals.

3.2 Discussion of materials and methods used for consolidation of plaster

A great variety of natural and synthetic materials have been used to consolidate architectural materials. However, compared to materials such as stone and wood, a very limited number of studies have been done to assess the conservation of plaster. Because architectural plaster may be made up of clayey soil, gypsum, or lime, they share similar properties with other building materials. Beaubien et al. remark that deteriorated plaster is often treated as limestone due to their chemical similarities. The primary difference between lime plaster and limestone lies in microstructural features such as grain size and porosity.⁵ The composition of earthen plaster, however, is often more similar to mud brick and adobe than it is to limestone. Thus studies on the consolidation of mud brick are useful in determining appropriate consolidating systems for earthen plasters. A review of consolidants used for the consolidation of plaster and related materials was

⁵ Harriet Beaubien, Carol A. Grissom, Lambertus van Zelst, Ghazi Bisheh, "Examination Report and Treatment Proposal for the Ain Ghazal Statuary Cache," (Conservation Analytical Laboratory, Smithsonian Institution, photocopy), 14.

undertaken in order to assess which organic and inorganic consolidants would be most appropriate for the consolidation of plasters from Çatalhöyük. This review consists of a discussion of the chemical processes which take place during consolidation, a survey of relevant case studies, and an assessment of the appropriateness of the consolidant for use at Çatalhöyük.⁶

3.2.1 Organic consolidants

Synthetic organic materials have been commonly used to consolidate architectural materials since the 1960s. The application of organic consolidants generally involves the deposition of a polymers which are not related chemically to the material to be treated and do not react with it. The polymers are either formed by pre-polymerization or polymerization in situ.⁷ In the first case, monomers of relatively low molecular weight are polymerized, this organic polymer resin is dissolved in a solvent, and the consolidating system is applied to the material. The polymer resin will remain in the material when the solvent evaporates. Alternately, monomers dissolved in a solvent can be applied directly to the material where they will polymerize in situ. Initiators, accelerators, and activators can be added to the monomer consolidating system to ensure polymerization or they will polymerize upon contact with atmospheric moisture. Monomer systems usually achieve greater depth of penetration than pre-polymerized systems because they are less viscous due to the lower molecular weight and smaller sized molecules.⁸

⁶ A more complete review of relevant case studies is given in Appendix E.

⁷ Giacomo Chiari, "Chemical Surface Treatments and Capping Techniques of Earthen Structures: A Long-Term Evaluation," in *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints* (Los Angeles: The Getty Conservation Institute, 1990), 268.

⁸ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 12.

Organic consolidants have found wide use because they greatly improve the mechanical strength of weak material and have significant consolidating value.⁹ Theoretically, they are also reversible, being soluble in the solvent which was used to deposit them in the treated material. In addition, many synthetic resins also act as adhesives, which is sometimes desirable.¹⁰ However, because they are composed of organic molecules, they have a tendency to degrade over time when exposed to oxygen and light, resulting in discoloration, loss of tensile strength, and brittleness.¹¹ Organic consolidants, especially pre-polymerized resins, also have a tendency to migrate back to the surface of the treated material as the solvent dissolves causing the formation of a thin consolidated crust and a film of resin on the surface.¹² Finally, the coefficients of thermal expansion of most synthetic organic resins are much larger than those of stone, architectural ceramics, earthen materials, and plaster.¹³ Stress which develops between the consolidated and unconsolidated material can lead to detachment of a section of the material or damage to the material.

There are two classes of organic consolidants based on polymer structure: thermoplastic consolidants and thermosetting consolidants. Thermoplastic consolidants are two-dimensional linear chains made up of monomeric units linked together by weak

⁹ P. Rossi-Doria, M. Tabasso, and G. Torracco, "Note on Conservation Treatments of Stone Objects," Section 6.12 in *The International Symposium on the Deterioration and Protection of Stone Monuments* (Paris: RILEM, 1978), 7.

¹⁰ Giacomo Chiari, "Chemical Surface Treatments and Capping Techniques of Earthen Structures: A Long-Term Evaluation," in *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints* (Los Angeles: The Getty Conservation Institute, 1990), 268.

¹¹ Giorgio Torracca, *Porous Building Materials: Materials Science for Architectural Conservators*, 3rd ed. (Rome: ICCROM, 1988), 127.

¹² Giacomo Chiari, "Chemical Surface Treatments and Capping Techniques of Earthen Structures: A Long-Term Evaluation," in *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints* (Los Angeles: The Getty Conservation Institute, 1990), 268.

¹³ *Ibid.*, 268.

molecular forces.¹⁴ These resins become plastic upon heating and rigid when cooled. They remain soluble in various solvents so that, in theory, they can be removed from a material. Because of their large molecular size they do not easily penetrate into small pores and tend to accumulate near the surface of a material. The thermoplastic resins most often used to consolidate plaster and related materials are acrylics, polyethylenes, nylon, polyvinyl acetates, polyvinylchlorides, polyisocyanates, and polystyrenes. Of these, only the acrylics have been widely used for the consolidation of plaster.

Thermosetting consolidants are three-dimensional, cross-linked networks composed of monomeric units joined by strong chemical bonds.¹⁵ They are generally irreversible because of these strong bonds, and are stronger than thermoplastics. Although thermosetting resins are harder and stronger than thermoplastic resins, they are also more brittle.¹⁶ Thermosetting resins are technically insoluble in all solvents but have the ability to swell to form a gel in some solvents or to be chemically broken down by certain reagents so that they can form soluble products.¹⁷ The most important thermosetting consolidants are epoxies, polyesters, and polyurethanes. None of these have found popular use for the consolidation of plaster.

¹⁴ Giorgio Torraca, *Porous Building Materials: Materials Science for Architectural Conservators*, 3rd ed. (Rome: ICCROM, 1988), 123-132.

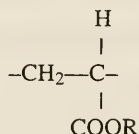
¹⁵ *Ibid.*, 125-127.

¹⁶ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 13.

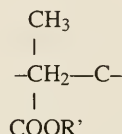
¹⁷ Giorgio Torraca, "Synthetic Materials Used in the Conservation of Cultural Property," appendix in *The Conservation of Cultural Property* (Paris: UNESCO, 1968), 306.

3.2.1.1 Acrylic resins

Acrylic polymers used as consolidants are based on two families of monomers: the acrylates and the methacrylates.



chain of polyacrylate



chain of polymethacrylate

The chemical properties of the consolidant depend on the type of monomer and how it is used in a polymer system, the type of alkyl group (R and R'), and the size and shape of the polymer molecules.¹⁸ Nonetheless, most acrylic resins share certain properties. They can be dissolved in many solvents, and they maintain their solubility as they age so that they are somewhat reversible. Acrylic polymers are relatively stable in the presence of oxygen and ultraviolet radiation. They also have good adhesive properties due to the presence of polar side groups. Acrylic resins, like all other thermoplastic polymers, cannot be used structurally and tend to creep over time.

Monomers which are polymerized in situ have been used as consolidants in place of pre-polymerized resins.¹⁹ They have the advantage of obtaining a greater depth of penetration because the monomer solutions have a lower viscosity than comparable polymer solutions. They are polymerized in situ using ultraviolet and gamma radiation or chemical catalysts such as peroxides, or through precipitation polymerization. In the latter case, the monomer is carried into a material in a liquid which is a solvent for the

¹⁸ Marisa Laurenzi Tabasso, "Acrylic Polymers for the Conservation of Stone: Advantages and Drawbacks," *APT Bulletin* 26, no 4 (1995): 17-18.

¹⁹ *Ibid.*, 19-20.

monomer but not for the resulting polymer so that the resin will solidify. One of the main drawbacks of in situ polymerization is the cracking that can occur in a material due to stresses released during the process. Controlled temperatures are necessary for the polymerization process to occur.

Both polymer and copolymer acrylic resins have been used to consolidate plasters. Methyl methacrylate and butyl methacrylate are common stone and concrete consolidants.²⁰ A study of the consolidating effect of polybutyl methacrylate using two different solvents showed that it effectively restores the cohesive strength and decreases the hygroscopicity of loess plaster made of both burnt and unburnt clay.²¹ The most widely used acrylic resin used in the conservation of plasters, however, is the copolymeric resin Acryloid® (or Paraloid®) B-72. Acrylic copolymers consist of two or more different acrylic monomers joined together into a polymer chain. The most common monomers used as acrylic copolymers are methyl acrylate, ethyl acrylate, methyl methacrylate, and butyl methacrylate.

Acryloid® B-72 is a copolymeric resin consisting of methyl acrylate and methylacrylate in a 30:70 molar ratio. It is dissolved in various organic solvents, toluene and xylene being the most common when used as a consolidant.²² It has the advantage of being an adhesive so that it is used to reattach flaking plaster and paint and will not promote detachment. It has also been combined with other resins to impart better adhesive properties. Its solubility in several solvents means that materials treated with

²⁰ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 13.

²¹ N. G. Gerassimova and E. P. Mel'nikova, "The Effect of the Treatment with Polybutyl Methacrylate solutions on Physical and Mechanical Properties of Loess Plaster," in *ICOM Committee for Conservation, 5th Triennial Meeting, Zagreb, 1-8 October 1978: Preprints* (Paris: International Council of Museums, 1978).

²² C.V. Horie, *Materials for Conservation: Organic Consolidants, Adhesives and Coatings* (London: Butterworths & Co., Ltd., 1987), 106.

Acryloid® B-72 can be retreated with greater effectiveness. However, its solubility in water means that material treated with B-72 tends to lose any hydrophobic properties imparted upon consolidation as the duration and number of wetting and drying cycles is increased.²³ Another major drawback of B-72 is its poor depth of penetration, although Beaubian et al. report 30 mm of penetration using a 5% solution (w/v) of B-72 in toluene to treat marl-lime plaster figures from 'Ain Ghazal, Jordan.²⁴ In a study of the susceptibility of various polymers and resins to biodeterioration, Koestler and Santoro found that Acryloid® B-72 "showed moderate resistance."²⁵ Under most circumstances Acryloid® B-72 can be easily applied by brushing or spraying and produces a stable consolidating material.

Acryloid® B-72 has been used to consolidate both lime and earthen plasters. In testing numerous consolidant systems for the treatment of a cache of plaster statues composed of a material similar to the Çatalhöyük plasters, Boulton achieved excellent results with a 5% solution of B-72 in toluene solvent.²⁶ Szabó reports that there was no change in optical properties and hydrophobicity was increased when adobe walls with mural paintings were treated with a 5% solution of B-72 in xylene.²⁷ The advantages of

²³ A. E. Charola, M. Laurenzi Tabasso, and O. Santamaria, "The Effect of Water on the Hydrophobic Properties of an Acrylic Resin," in *Vth International Congress on Deterioration and Conservation of Stone*. Lausanne, 25-27.9.1985, assembled by S. G. Félix, 739-747 (Lausanne: Presses polytechniques romandes, 1985).

²⁴ Harriet Beaubian, Carol A. Grissom, Lambertus van Zelst, and Ghazi Bisheh, "Examination Report and Treatment Proposal for the Ain Ghazal Statuary Cache," (Conservation Analytical Laboratory, Smithsonian Institution, photocopy), Appendix B, 22.

²⁵ Robert J. Koestler and Edward D. Santoro, *Assessment of the Susceptibility to Biodeterioration of Selected Polymers and Resins* (Marina del Rey, CA: Getty Conservation Institute, Scientific Program, 1988), 51.

²⁶ Ann Boulton, "Some Considerations in the Treatment of Archaeological Plaster Figures from Ain Ghazal, Jordan," in *The American Institute for Conservation of Historic and Artistic Works. Preprints of Papers Presented at the Sixteenth Meeting, New Orleans, Louisiana, June 1-5, 1988*, edited by Sarah Z. Rosenberg (Washington, DC: The American Institute for Conservation of Historic and Artistic Works, 1988), 54.

²⁷ Zoltán Szabó, "The Conservation of Adobe Walls Decorated with Mural Paintings and Reliefs in

Acryloid® B-72 and its success as a consolidant for plasters make it a worthy material to test for the treatment of the Çatalhöyük plasters. It has been used to consolidate plasters similar to those of Çatalhöyük and its usefulness in hot climates, cited by Beaubian et al., is another advantage relevant to the work at the site.²⁸

3.2.1.2 Epoxy resins

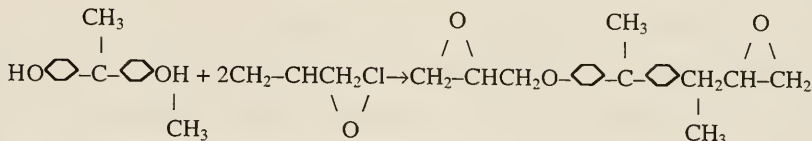
Although there has been little previous research using thermosetting resins in the treatment of plaster, the success of epoxy resins as a consolidant and adhesive for porous stone merits attention as a possible treatment for plaster. Epoxy resin consolidants are multiple part systems, consisting of the epoxide group, a hardener, and the solvent, and sometimes also requiring an accelerator. The epoxide group most often used in conservation is the diglycidyl ether of bisphenol A.²⁹ This can be produced either by the condensation of epichlorohydrin and bisphenol A or the hydrogenation of bisphenol A to 2,2-di (4-hydroxycyclohexyl) propane.³⁰ In the second reaction, the hydrogenated bisphenol A is combined with epichlorohydrin to form the diglycidyl ester of bisphenol A. the basic reaction is the following, with the formation of some by-products:

Peru," in *ICOM Committee for Conservation, 5th Triennial Meeting, Zagreb, 1-8 October 1978: Preprints* (Paris: International Council of Museums, 1978).

²⁸ Harriet Beaubian, Carol A. Grissom, Lambertus van Zelst, and Ghazi Bisheh, "Examination Report and Treatment Proposal for the Ain Ghazal Statuary Cache," (Conservation Analytical Laboratory, Smithsonian Institution, photocopy), 15.

²⁹ C.V. Horie, *Materials for Conservation: Organic Consolidants, Adhesives and Coatings* (London: Butterworths & Co., Ltd., 1987), 170.

³⁰ Evin Erder, "Consolidation and Adhesive Repair of Volcanic Tuff Case Study: Conservation of Volcanic Tuff at the Old Stone Church of Mission San Juan Capistrano, San Juan Capistrano, California," (master's thesis, University of Pennsylvania, 1995).



where C_6H_4 is either a benzene ring or cyclohexyl ring

The hardener transforms the epoxide group into a thermosetting molecule, usually without the use or formation of by-products. The hardeners that are most often used are Lewis acids and bases, inorganic hydroxides, primary, secondary, and tertiary amines, amides, phenols, and anhydrides.³¹ Organic solvents are necessary to reduce the viscosity of the resin system. The choice of solvent will affect the reaction between the epoxide and the hardener as well as the interaction between the resin and material to be treated. Epoxies are soluble in most common solvents. An accelerator may be necessary to increase the cross-linking reaction to a feasible rate. The choice of solvent will also affect the reaction.

The difficulty in preparing an epoxy resin treatment has meant that epoxies are often considered of secondary importance as consolidants. They also tend to discolor and are essentially irreversible, being insoluble in most solvents once cross-linking has occurred. However, they have been used with some success in treating friable stone, and if used properly, they confer much better strength and durability to the material than any other consolidant.³² Epoxy consolidants, as thermosetting resins, produce a cross-linked network structure which gives great stability. They also achieve deep penetration and good adhesion in many materials.

³¹ Giovanni G. Amoroso and Vasco Fassina, *Stone Decay and Conservation: Atmospheric Pollution, Cleaning, Consolidation and Protection* (Amsterdam: Elsevier Science Publishers, 1983), 311-312.

³² Charles Selwitz, "The Use of Epoxy Resins for the Stabilization of Deteriorated Masonry," APT Bulletin 26, no. 4 (1995): 28.

The effectiveness of treatment of friable plaster with epoxy resins has yet to be determined. Because epoxy resins act as both a consolidant and an adhesive, they may be useful in the treatment of flaking and crumbling plaster. Advantages such as low viscosity of the consolidating system and strong hydrophobic properties may outweigh disadvantages such as degradation and irreversibility.

3.2.2 Inorganic consolidants

Inorganic materials have been used as consolidants for many years under the premise that the best material to restore cohesion between friable particles is the material itself. Thus many inorganic consolidants are based on the same compounds that make up stone, plasters, and other materials. For example, calcium or barium hydroxides are used to consolidate calcareous stones such as limestone and marble, and siliceous consolidants are used with sandstones.³³

The history of use of inorganic consolidants has been marked by some successes and a great deal of failures.³⁴ They are generally more durable than organic consolidants, partly because of the structural stability they achieve with the material to be consolidated.³⁵ However, they are less elastic and do not penetrate as deeply as organic consolidants.³⁶ They also tend to form soluble salts and precipitated crystals as by-products and may cause unacceptable color changes.³⁷

³³ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 3.

³⁴ Ibid., 3.

³⁵ P. Rossi-Doria, M. Tabasso, and G. Torracco, "Note on Conservation Treatments of Stone Objects," Section 6.12 in *The International Symposium on the Deterioration and Protection of Stone Monuments* (Paris: RILEM, 1978), 7.

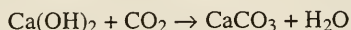
³⁶ Ibid., 7.

³⁷ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 3.

The most promising organic materials used for the consolidation of stone, earthen materials, plaster, and other substances are the alkaline earth hydroxides: calcium hydroxide and barium hydroxide. Siliceous consolidants such as alkali silicates and fluosilicate and aluminate compounds have also been used but display disadvantages which make them ineffective treatments.³⁸ These completely inorganic siliceous consolidants and a number of other substances, including hydrofluoric acid, aluminum sulfate, zinc and aluminium stearates, phosphoric acid and phosphates, have been used in the past to consolidate stone but will not be considered here due to their lack of success and untested use for the treatment of plaster.³⁹

3.2.2.1 Calcium hydroxide

Calcium hydroxide used in a saturated solution with water, called limewater, has been used for centuries to treat limestone and lime plasters. The calcium hydroxide reacts with carbon dioxide in the atmosphere to form calcium carbonate, the chemical equivalent of limestone:



Because the consolidating product which binds the detached particles together is the same as the original material, the treated material is assumed to have similar chemical, physical, and mechanical properties. However, research indicates that consolidation may rely on solubilization and redeposition of calcium sulfate as much as the carbonization of calcium hydroxide.⁴⁰

³⁸ P. Rossi-Doria, M. Tabasso, and G. Torracco, "Note on Conservation Treatments of Stone Objects," Section 6.12 in *The International Symposium on the Deterioration and Protection of Stone Monuments* (Paris: RILEM, 1978), 9.

³⁹ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 4.

⁴⁰ John Fidler, "Lime Treatments: Lime Watering and Shelter Coating of Friable Historic

Based on research in Bristol, Bath, and Oxford in the United Kingdom in the 1950s onward, Robert Baker helped to revitalize the lime method process of treating limestone stonework while conserving the figural statuary of the west front of Wells Cathedral in the late 1970s and early 1980s.⁴¹ Consolidation is one step in the process, which includes cleaning by lime poulticing, consolidating using limewater, grouting and filling damaged areas with lime mortar, and adding a shelter coat of lime plaster. The limewater is applied directly to the cleaned material, which can either be limestone or lime plaster.⁴² Cedillo-Alvarez reports that limewater has been used to consolidate lime plaster and stucco work at various archaeological sites in Mexico, although the success of the treatment is not discussed.⁴³

Consolidation with limewater has showed promising results in the United Kingdom, although its efficacy is still a topic of great debate. Numerous applications (almost forty applications over several days) of limewater are necessary to achieve minimal penetration.⁴⁴ Because the solidification of calcium carbonate depends on carbon dioxide in the air, most of the lime is deposited in the two or three millimeters of material near the surface.⁴⁵ In addition, it is still unclear how dependent consolidation is upon the skill of the conservator, lime poulticing, and the other procedures in the

Masonry," *APT Bulletin* 26, no 4 (1995): 52-53. Fidler cites research which indicates that the application of distilled water can have as much of a consolidating effect as limewater, and that more soluble limestones, such as magnesian limestone, tend to harden more than other limestones.

⁴¹ Ibid., 51.

⁴² Ibid., 52.

⁴³ Luciano Cedillo-Alvarez, "Stucco: A Report on the Methodology Developed in Mexico," In *In Situ Archeological Conservation: Proceedings of Meetings April 6-13, 1986*, edited by Miguel Angel Corzo, 90-97 (Los Angeles: The Getty Conservation Institute, 1987).

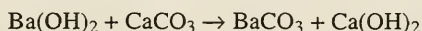
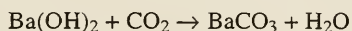
⁴⁴ John Fidler, "Lime Treatments: Lime Watering and Shelter Coating of Friable Historic Masonry," *APT Bulletin* 26, no 4 (1995): 52.

⁴⁵ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials." (master's thesis, University of Pennsylvania, 1992), 7-8.

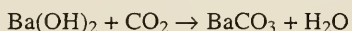
treatment process.⁴⁶ Finally, although appropriate for the consolidation of lime plasters, limewater is not suitable for treating earthen plasters which contain a great deal of non-calcareous material and clays which may swell when treated with a water-based system.

3.2.2.2 Barium hydroxide

Treatment of friable carbonate stones and lime plasters with barium hydroxide relies on the same principle as treatment with calcium hydroxide, barium being chemically similar to calcium. There are two consolidating mechanisms, one based on the reaction of barium hydroxide with carbon dioxide in the atmosphere and the other based on the reaction with calcium carbonate in the material:



Lewin has suggested that the addition of urea and glycerine to the mixture can improve the consolidating success of barium hydroxide. Urea allows deep penetration of the hydroxide, regulates the pH of the system, and provides an additional source of carbon dioxide. The urea is hydrolyzed, producing carbon dioxide in the interior so that carbonation of barium hydroxide can occur deep within the friable material:

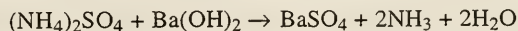
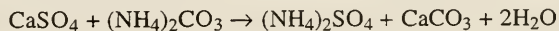


In addition, the application of an ammonium carbonate poultice will assist barium hydroxide to transform soluble calcium sulfates into barium sulfate, which is very insoluble and more resistant to acidic attack.⁴⁷ This process takes place according to the

⁴⁶ Ibid., 8.

⁴⁷ Ibid., 8.

following reactions, with the excess ammonium carbonate autodecomposing into volatile ammonia, carbon dioxide, water which leave the material:



The glycerine slows down the rate of reaction so that the barium hydroxide solution can be kept in contact with the material to be treated for several weeks, which is necessary for large-scale applications.⁴⁸

In addition to being promoted as an effective consolidant for marbles and calcitic limestones, the barium treatment process, sometimes called the Florentine Method, has been used to consolidate fresco and plaster. Arthur H. Church patented the use of barium hydroxide in solution for stone preservation in 1862.⁴⁹ The modifications made by Lewin in the mid-1960s and early 1970s caused a renewed interest in the treatment. More recently, the barium treatment has been used to consolidate frescos in Italy. In these latter applications, the barium process has given potentially useful results. It has restored cohesion of particles within the fresco layer and arrested the sulfation process without altering the appearance of the pigments.⁵⁰

The use of the barium method has disadvantages which make it inappropriate in some applications. Most importantly, it is only appropriate for the consolidation of some marbles, limestones, and lime plaster. It can be used to treat gypsum plaster, but

⁴⁸ Giovanni G. Amoroso and Vasco Fassina, *Stone Decay and Conservation: Atmospheric Pollution, Cleaning, Consolidation and Protection*, (Amsterdam: Elsevier Science Publishers, 1983), 311-312.

⁴⁹ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania, 1992), 8.

⁵⁰ Mauro Matteini, "In Review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments," in *The Conservation of Wall Paintings: Proceedings of a Symposium Organized by the Courtauld Institute of Art and the Getty Conservation Institute, London, July 13-16*, edited by Sharon Cather (Marina del Rey, CA: Getty Conservation Institute, 1991), 146.

excessive use of barium hydroxide will cause deterioration of the plaster due to excessive conversion of the sulfate.⁵¹ It has not been and should not be used to treat earthen plasters or mud brick because of the incompatibility of materials. In addition, the kinetics of the consolidating mechanisms are still being studied so that the issues of treatment time and chemical concentrations, when used with any type of plaster or stone, are not yet completely understood.⁵² Also, discoloration due to the formation of white barium salts is always a risk. Finally, the caustic nature of barium hydroxide makes it dangerous.⁵³

3.2.3 Alkoxysilanes

Alkoxysilanes are a family of monomeric molecules which are partly organic and partly inorganic. The basic composition of all alkoxysilanes is a silane molecule attached to at least one alkoxy group by an ester link (Si–O–C). A silane is a compound which has a silicon chain to which hydrocarbon alkyl groups such as methyl (–CH₃) and ethyl (–C₂H₅) attach. The alkoxysilane is polymerized in the material through the process of hydrolysis and condensation. A network of siloxane monomers (–Si–O–Si–), stoichiometrically equivalent to silica, is formed after these two reactions take place. The

⁵¹ Edward V. Sayre, "Deterioration and Restoration of Plaster, Concrete and Mortar," in *Preservation and Conservation: Principles and Practice. Proceedings of the North American International Regional Conference. Williamsburg, Virginia, and Philadelphia, Pennsylvania, September 10-16, 1972*, edited by Sharon Timmons (Washington, DC: The Preservation Press, 1976), 198.

⁵² Mauro Matteini, "In Review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments," in *The Conservation of Wall Paintings: Proceedings of a Symposium Organized by the Courtauld Institute of Art and the Getty Conservation Institute, London, July 13-16*, edited by Sharon Cather, (Marina del Rey, CA: Getty Conservation Institute, 1991), 144-145.

⁵³ Isil Öztürk, "Alkoxysilanes Consolidation of Stone and Earthen Building Materials," (master's thesis, University of Pennsylvania. 1992), 10.

rate of polymerization and the final structure depend on the amount of water used in the reaction, the type of catalyst, and the solvent of the consolidating system.⁵⁴

The use of alkoxysilane consolidants dates to the first quarter of the nineteenth century, but since the 1960s, they have achieved renewed popularity and commercial success.⁵⁵ They have been used with much success on a variety of materials, including plasters, and are thus of great importance in the present study. They were originally conceived for the conservation of sandstones, with the assumption that the same siliceous material that constitutes the original material is being reintroduced into the treated material. They have since been applied to calcareous stones, earthen architecture, and various types of plaster.

In general, alkoxysilanes can penetrate deeply into a material because of their low viscosity, small molecular size, and slow rate of evaporation. They also reportedly coat pores rather than fill them, allowing retreatment while not interfering with water vapor transmission. One major disadvantage of alkoxysilanes is the darkening effect that they have on most materials, although this tends to lessen with the passage of time. In addition, high cost and toxicity compromise convenience of application. Although the susceptibility of various alkoxysilanes to biodeterioration has been assessed, the results of these tests have been divergent and further research is needed to determine the role of the different components in the degradation cycle.⁵⁶

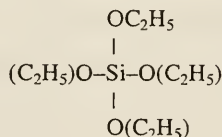
The alkoxysilane that has most often been used for the consolidation of plaster is tetraethoxysilane, commonly called ethyl silicate. Ethyl silicate may also be referred to as

⁵⁴ Ibid., 11.

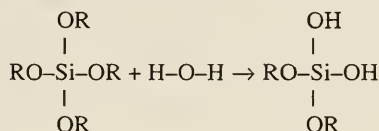
⁵⁵ Ibid., 11.

⁵⁶ Robert J. Koestler and Edward D. Santoro, *Assessment of the Susceptibility to Biodeterioration of Selected Polymers and Resins* (Marina del Rey, CA: Getty Conservation Institute, Scientific Program, 1988).

silicic acid ester, silicon ester, or tetra(ethyl)orthosilicate (TEOS). Ethyl silicate is produced by the reaction of silicon tetrachloride (SiCl_4) with ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$) which gives the following compound:



The hydrolysis reaction that occurs is the following:



where R is (C_2H_5)

When hydrolysis is complete, the monomer will condense and the polymer network structure will form. This network is totally irreversible.

Ethyl silicate has been used to consolidate lime and earthen plasters in addition to its more common application to stone and mud brick. Beaubian et al. judged Conservare® OH, the most common commercial ethyl silicate product, to be the best consolidant for the treatment of plaster figures from 'Ain Ghazal, Jordan.⁵⁷ Its consistent depth and evenness of penetration and increase in tensile strength were its major advantages. Although changes in color due to residual catalyst has been suggested as a possible long term effect, the 'Ain Ghazal study has not had this problem. Follow up investigation of earthen plaster reliefs at Chan Chan consolidated with ethyl silicate 25

⁵⁷ Harriet Beaubian, Carol A. Grissom, Lambertus van Zelst, and Ghazi Bisheh, "Examination Report and Treatment Proposal for the Ain Ghazal Statuary Cache," (Conservation Analytical Laboratory, Smithsonian Institution, photocopy), 23.

years after treatment by Giacomo Chiari was also positive, although the lack of adhesion to the mud brick substrate was noted.⁵⁸ Ethyl silicates are often used to consolidate mud brick, which is somewhat similar, compositionally, to earthen plaster.

Past success of treating earthen plasters indicates that ethyl silicate should be considered as a consolidation treatment for the Çatalhöyük plasters. One of the major factors in consolidating the wall and relief plasters at Çatalhöyük is the need for deep penetration in order to fully consolidate all of the layers of plaster, which are in excess of 150 in some cases. As Torracca points out, ethyl silicate used to treat earthen materials is appealing because the final product after hydrolysis and condensation will connect to clay silicates and will have an open porous structure.⁵⁹

⁵⁸ Giacomo Chiari, "Treatment of Adobe Friezes in Peru, in Third International Symposium on Mudbrick (Adobe) Preservation, edited by Okan Üstünkök and Emre Madran (Ankara: ICOM/ICOMOS, 1980).

⁵⁹ Giorgio Torracca, "An International Project for the Study of Mud-Brick Preservation," in *1970 New York Conference on Conservation of Stone and Wooden Objects*, 2nd ed., volume 1, *Conservation of Stone* (London: International Institute for the Conservation of Historic and Artistic Works, 1971), 51.

Chapter Four: Laboratory Testing Program

In devising a treatment for the conservation of architectural plasters at Çatalhöyük, a methodology based on an understanding of the structure and composition of the plasters, identification of the deterioration problem, evaluation of previous research, and assessment of different consolidation treatments has been used. These are not tasks which are independent of each other, but rather, they are intricately connected. The choice of which consolidants to test depends on the characterization of the plasters and on previous research on plaster consolidation. The tests which are critical in the evaluation of the effectiveness of consolidation are based on the identification of the deterioration problems and the conservation goals for the site.

Three classes of consolidants which have shown some success in plaster conservation were selected for testing. The comparative effectiveness of an epoxy resin, an acrylic resin, and an alkoxysilane were assessed based on a number of standard tests. The alkoxysilane was used with three different solvent systems, and two of the alkoxysilane mixtures were applied following preconsolidation with the acrylic resin. By evaluating the physical, mechanical, and chemical properties of the plasters before and after treatment, recommendations for intervention can be made. The ultimate goal of any intervention is to conserve the architectural plasters as an integral element in the interpretation of Çatalhöyük.

4.1 Identification of the deterioration problem

Macroscopic examination of bulk plaster samples and microscopic examination of cross-sections prepared from these samples indicate that the Çatalhöyük plasters are suffering loss of cohesive strength within a single layer and, to a lesser extent, are delaminating at the interfaces between different plaster layers. The loss of cohesion and cracking across plaster layers is evident in each type of plaster among the samples. Most of the delamination is occurring between those layers which are farthest from the mud-brick substrate and may be due to the effects of burial-related factors such as moisture and salts on the reactive smectite-chlorite clays. This pattern of deterioration is evident from *in situ* examination of the plasters as well.

Undoubtedly, some of the plasters would have experienced some cracking immediately after application. Cracking can occur if the plaster is allowed to dry too rapidly or if it is applied to an incompatible surface. An example of the latter case may be seen in one of the cross sections of plaster where a large crack occurs directly above a layer with an uncharacteristically high percentage of coarse material. The coarse material, mostly quartz and feldspar fragments, may have provided an unsuitable surface for adhesion of the following layer resulting in cracking and delamination. Subsequent exposure to the environment while the site was occupied would have led to further deterioration of the architectural plaster.

The weight of the soil which has covered the plasters for thousands of years might also affect their condition. Turkey is an extremely seismic country and undoubtedly there has been movement of the soil covering Çatalhöyük. This movement against the surviving fragments might lead to cracking or crushing of the component layers.

Macrobiological growth has had a role in the deterioration process as well. At least three of the bulk plaster samples contain secondary vegetation which was not added during initial manufacture. In one of these samples, an extensive root system has caused complete separation between layers. Plant systems that become attached to the plasters and are able to grow will cause delamination between layers and loss of cohesion between the components within a layer as the plant expands and exerts pressure on the plaster layers. Plants may also deposit salts and other materials as a byproduct of the nutrients they use as nourishment. These salts may migrate through the plaster if solubilized by water and crystallize upon evaporation of the water. Crystallization between and within layers can cause delamination and loss of cohesion because of the change in dimensional forces.

Another cause of the deterioration evident in the plaster samples is the drastic environmental change which the material has been subjected to upon excavation. Little conservation effort has been directed toward the plasters that have been exposed to the open environment since excavation in the 1960s. The plasters were formerly protected by a relatively stable covering of earth which minimized the effects of fluctuations in atmospheric temperature and humidity. However, once exposed to the open air, the plasters and other materials of Çatalhöyük are subjected to greater stresses due to fluctuating environmental conditions. Hot dry summers are typically preceded by rainy springs and severe winters with temperatures below freezing and heavy rainfall. The material used in the manufacture of the plasters is extremely water-sensitive, and even small changes in relative humidity can result in damage to the structure of the plasters. Loss of cohesion also occurs when the moisture retained by the clay components in the plaster as a binding material evaporates causing dehydration and cracking. The

detachment of wall plasters once exposed to the open environment was immediately evident during the earlier excavation and continues to occur in the present.

A comprehensive conservation program is being devised for the site which will allow stabilization and conservation of the architectural material unearthed during excavation of Çatalhöyük to proceed simultaneously with excavation. *In situ* conservation, followed by lifting and relocation of portions of rooms after they have been researched archaeologically is necessary in order to conserve associated features while more and more of the site is being excavated. The purpose of the plaster consolidation, then, is to increase the intergranular strength of the plaster components so that the multiple plaster layers will remain intact while exposed to the environment during excavation and as sections of the rooms containing plastered walls and reliefs are lifted and relocated. Also critical to the assessment of treatments in the conservation of the plaster is the effect that consolidation will have on subsequent detachment of layers with mural paintings.

4.2 Selection of treatments

Based on the nature of the Çatalhöyük plasters and the review of the materials previously tested or applied in plaster consolidation, three products were identified as potential consolidants: a hydrogenated bisphenol A-epichlorohydrin epoxy resin (Eponex® 1510), a methyl acrylate-ethyl methacrylate copolymeric resin (Acryloid® B-72), and a tetraethyorthosilicate, commonly called an ethyl silicate (Conservare® Stone Strengtheners OH). Conservare OH comes premixed in a methyl ethyl ketone solvent. There are also small amounts of acetone and ethanol in the consolidating system. The acrylic resin was mixed as 5% solution (w/v) in toluene. Toluene was selected as the

solvent for Acryloid® B-72 based on its low viscosity and evaporation rate. In addition, after extensive testing of consolidants for use with marly soil plaster statuettes from 'Ain Ghazal, Jordan, a 5% solution of Acryloid® B-72 in toluene was judged to be among the most effective treatments.¹ An epoxy resin was considered because of its effectiveness in treating friable stone such as tuff.² Eponex® 1510 is the only epoxy resin which can be sprayed, a practical consideration applicable to the site of Çatalhöyük. The resin was mixed as a 10% solution (w/w) in isopropanol. Isopropanol was chosen as the solvent for the epoxy resin based on tests currently being conducted with epoxy resin consolidants by the Getty Conservation Institute.³ Toluene, which has been mixed with the isopropanol as a solvent, prevents deep penetration of the consolidant system and thus was not used with the epoxy resin. Jeffamine® T-403 was added as a hardener and Jeffamine® 399 was used as an accelerator.

The three consolidant systems were first tested on Çatalhöyük plaster cut into small cubes roughly one inch per edge in order to identify any immediately apparent problems that the chosen consolidants might present. Each consolidant was tested on two different samples. The cubes were partially immersed in the consolidant so that it covered about half of the sample. When the consolidant stopped rising in the sample the cubes were turned over. After complete penetration of the consolidant, the samples were

¹ Ann Boulton, "Some Considerations in the Treatment of Archaeological Plaster Figures from Ain Ghazal, Jordan," in *The American Institute for Conservation of Historic and Artistic Works. Preprints of Papers Presented at the Sixteenth Meeting, New Orleans, Louisiana, June 1-5, 1988*, edited by Sarah Z. Rosenberg (Washington, DC: The American Institute for Conservation of Historic and Artistic Works, 1988), 38-57.

² Evin Erder, "Consolidation and Adhesive Repair of Volcanic Tuff Case Study: Conservation of Volcanic Tuff at the Old Stone Church of Mission San Juan Capistrano, San Juan Capistrano, California," (master's thesis, University of Pennsylvania, 1995).

³ Rakesh Kumar, personal communication with Veronica Aplenc, 9 April 1996.

removed from the liquid and allowed to air cure. After one day, the samples showed no signs of deterioration due to the consolidant system.

Upon consolidation of the samples to be used in the laboratory testing program, however, several of the samples were damaged due to the reaction of the clays in the plaster with the solvents in the different systems. After an evaluation of the effects of different solvents on the plasters, methyl ethyl ketone, isopropanol, ethanol, and acetone were judged to be detrimental to the plasters. Mineral spirits, both odorless and naphtha, and toluene did not harm the samples.

Due to the varying effect of the solvents on the condition of the plasters, several additional consolidation systems were chosen for evaluation. It was decided to evaluate the effects of preconsolidation with an acrylic resin, which generally does not achieve great depth of penetration, followed by an ethyl silicate, which generally is very successful in consolidating porous materials. An ethyl silicate without the methyl ethyl ketone solvent (Conservare® OH40 Stone Strengthener) and an ethyl silicate monomer solution (T-1919 Conservare® OH Stone Strengthener) were used both in isolation and after preconsolidation with the acrylic resin consolidant (Acryloid® B-72).

4.3 Consolidation

4.3.1 Sample preparation

Although many plaster fragments from Çatalhöyük were provided to the Architectural Conservation Laboratory for characterization and consolidation testing, they were not all suitable for use in an experimental testing program. Because there were few relief plasters available, only wall plasters could be used. The samples chosen for testing had to have certain minimum dimensions based on the standardized tests to be

performed. Many fragments were unsuitable because they were not more than a 1/2 inch thick, the minimum needed for the testing. Other samples were too weak to tolerate cutting.

The limited number of samples suitable for testing affected the design of the experimental testing program. Tests that are critical in the evaluation of consolidation efficacy, such as water vapor transmission, could not be performed because either enough material was not available or the proper shapes could not be cut.

The samples to be used in the experimental program were cut to the dimensions required for the tests to be performed after consolidation.⁴ (Figures 16 and 17). Cutting the plasters proved problematic because of the heterogeneous nature of the material. The most effective way to cut them was with a band saw using a 1/64 inch blade. Much material was lost during cutting because of the presence of inclusions and planes of weakness within the plasters. Eventually enough plaster was cut so that three control samples (untreated) and three samples for each consolidant were available for each test to be performed. They were labeled using a pencil and color pens. Before consolidation the samples were allowed to sit uncovered in the laboratory for at least 24 hours to absorb as much moisture as they might be expected to in normal field conditions. The following amount of material was prepared for consolidation and the laboratory testing program:

⁴ The samples were cut by Alex Gontar of the Civil Engineering Department, Drexel University who shared my sadness as many of the plaster samples uncontrollably disintegrated during cutting.

Samples Prepared for Experimental Testing Program		
Size	Quantity	Test(s) to be Performed
2" x 1" x 1.25"	7	Depth of penetration SEM analysis of consolidating effectiveness Change in optical properties
3" x 1" x 0.5"	16	Abrasion resistance
1" x 1" x 1"	24	Wet/Dry cycling
between 0.5" x 0.5" x 0.5" and 1" x 1" x 1"	24	Change in bulk specific gravity

Table 7

4.3.2 Consolidant preparation and application

The Conservare Stone Strengthener consolidants are sold as pre-mixed solutions of ethyl silicate and their solvents. No further preparation is necessary. However, the acrylic resin and the epoxy resin used in the testing program had to be mixed to the desired solution. Acryloid® B-72 is sold as 100% solid material. It was mixed with toluene to give a 5% (w/v) solution. This was done by suspending the solid material wrapped in thick mesh gauze in a glass container containing the appropriate amount of solvent and mixing occasionally. In an air-tight container, this can be stored for an extended period of time. The epoxy resin used was mixed with a hardener (Jeffamine® T-403), an accelerator (Jeffamine® 399), and a solvent (isopropanol). To obtain a 10% (w/w) solution, the parts by weight necessary are 100 parts Eponex® 1510, 37 parts Jeffamine® T-403, 10 parts Jeffamine® 399, and 1323 parts isopropanol. The

Eponex® 1510 is mixed into the solvent first, followed by the hardener, and finally the accelerator. This mixture should be used as soon as possible after preparation.

The samples to be consolidated by the two preconsolidation systems were first preconsolidated with the acrylic resin by partial immersion to insure complete penetration. The samples were set on glass beads in a glass tray filled with enough consolidant to cover 1/2 to 2/3 of the sample. When the consolidant stopped rising in the sample through capillary action, the sample was turned over and allowed to absorb the Acryloid® B-72 consolidant for an equal amount of time. The samples were allowed to cure in the laboratory environment for 60 hours at roughly 65 to 70 degrees Fahrenheit and 20 to 30 percent relative humidity.

All of the samples, save for those to be used to assess depth of penetration, were also consolidated by partial immersion. (Figure 18). This method of application was completed for each of the samples, including those already preconsolidated with the acrylic resin. The samples were covered loosely with plastic wrap for 48 hours after consolidation to delay the evaporation of the solvent and then allowed to cure uncovered for four weeks

Consolidant was brushed on the samples used for depth of penetration testing, following the manufacturer's application procedures. Depth of penetration is a measure of how well a consolidant will penetrate a material based on the situation in the field. It can only be correlated with field conditions if the method of application is similar to what will actually be done in the field. For the Conservare® Stone Strengtheners products, the application procedure involved cycles consisting of three saturating applications, five minutes apart. After each cycle, the sample was allowed to sit for 20 to 30 minutes. Cycles were applied until consolidant rested on the surface of the sample, unabsorbed, for

20 to 30 minutes after the previous cycle. Between each cycle of Conservare® Stone Strengthener application, the sample was covered loosely with plastic wrap. The acrylic resin and the epoxy resin were continuously brushed on until the liquid puddled on the surface of the sample. All of the consolidants were brushed on the plaster face which would be treated during field application. (Figure 19).

4.4 Experimental testing program

The experimental testing program was designed to evaluate how well each potential consolidant meets the standard performance criteria. Due to the limited number of suitable samples, not all of the performance criteria could be assessed. The testing program reflects the need to evaluate the properties of consolidated material that are most critical given the conditions that exist at Çatalhöyük.

Sufficient depth of penetration is critical to an effective treatment of the Çatalhöyük plasters. Because of the thickness of the plasters in some areas, complete penetration to the mud brick substrate cannot realistically be achieved. Thus, the depth of penetration achieved using the different consolidants will be evaluated to determine if it is sufficient to prevent the formation of a thin surface crust which is likely to delaminate from the material underneath, leaving it vulnerable to continued deterioration. The test used for depth of penetration is the iodine vapor test developed by Rakesh Kumar and William S. Ginell of the Getty Conservation Institute.⁵ (Figure 23).

⁵ Rakesh Kumar and William S. Ginell, "A New Technique for Determining the Depth of Penetration of Consolidants into Limestone using Iodine Vapor," in *The American Institute for Conservation of Historic and Artistic Works. Abstracts of Papers Presented at the Twenty Second Annual Meeting, Nashville, Tennessee, June 6-11, 1994* (Washington, DC: American Institute for Conservation of Historic and Artistic Works, 1994), 70.

Measurement of strength is important in assessing the general consolidating value of a product. It was initially decided to test the modulus of rupture of the treated material as compared to untreated material. However, because of the damage caused to the samples during consolidation, it was decided to test abrasion resistance. (Figures 20 and 21). Abrasion resistance is measure of the intergranular cohesion within a porous material. Thus, it is a useful measure of the effectiveness of the consolidant. A modified version of ASTM test C 418: Standard Test Method for Abrasion Resistance of Concrete by Sandblasting was used.

Because of the extreme sensitivity of the Çatalhöyük plasters to water, a method of evaluating the effects of water on the treated plaster was considered important. A wet/dry cycle was used to determine how well the treated material tolerates constant wetting and drying, conditions that may exist if the plasters are to be exposed outside after excavation. (Figure 22). Thus the increase in hydrophobicity and weatherability of the treated material was evaluated. The test used was an adaptation of ASTM test D 559: Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures.

Changes in bulk specific gravity of the plasters will affect other treatment processes, particularly the lifting of wall sections. Thus, it was important to know how consolidation treatment will affect this physical property. This measurement was based on ASTM test D 2726: Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

Finally, changes in optical properties such as color were assessed using Munsell color chips. The samples tested for of depth of penetration were used for this comparison because they represent the field application techniques and the depth of penetration test is reversible.

4.5 Evaluation of test results

The results of the experimental testing program indicate that the consolidation of the plasters of Çatalhöyük must take into account many considerations (Procedures and Data in Appendix F). There is no clear choice of which material most effectively consolidates the plasters based on evaluation in the laboratory. Although ethyl silicates and the acrylic resin provide good resistance to mechanical abrasion and wet/dry cycling, the depth of penetration achieved by the acrylic resin alone does not seem to be sufficient for the case of the Çatalhöyük plasters and change in color caused by the ethyl silicate solutions may be unacceptable. In addition, the trace amounts of ethanol and acetone in the ethyl silicate systems damage the plasters by causing the clays to swell. The exception to this is the ethyl silicate monomer which performs well in abrasion and weatherability tests, has sufficient depth of penetration, and does not darken the plasters like the other ethyl silicates do or cause swelling and delamination.

depth of penetration: The staining caused by the reaction of the iodine vapor with the different consolidants is uneven in most cases. It tends to occur in zones parallel to the plaster layers and to weaken at depths greater than one centimeter. The greatest depth of penetration was achieved by the ethyl silicate systems. Whereas pretreatment of the sample treated ethyl silicate in mineral spirits using the acrylic resin as a preconsolidant seemed to increase depth of penetration, preconsolidation of the ethyl silicate monomer sample decreased the depth of penetration. The epoxy resin had sufficient depth of penetration, and the acrylic resin by itself had the least.

abrasion resistance: The ethyl silicate systems in mineral spirit and methyl ethyl ketone solvents and the acrylic resin in toluene reduced the amount of deterioration due to mechanical abrasion when subjected to blasting with aluminum oxide powder. However,

according to statistical analysis, only the acrylic resin-treated sample had a significant increase in abrasion resistance. There was almost no difference in resistance to abrasion between the untreated samples and those samples treated with the epoxy resin and the ethyl silicate monomer. Likewise, preconsolidation with the acrylic resin did not impart additional abrasion resistance, nor did it decrease resistance. The results from the two preconsolidated ethyl silicate monomer samples were significantly different to make the data statistically invalid.

wet/dry cycling: As expected, untreated samples disintegrated completely upon immersion in water. Unexpected, however, was the nearly identical phenomenon when samples treated with epoxy resin were put in the water bath. Overall, the acrylic resin-treated samples fared slightly better than the ethyl silicate-treated samples. Although the samples treated with acrylic resin suffered a greater weight loss than the samples consolidated with the different ethyl silicate systems, there was significantly less separation of layers and cracking across layers in the former set of samples. The samples consolidated with ethyl silicate in mineral spirits and the ethyl silicate monomer, both alone and after preconsolidation with the acrylic resin, suffered very little cracking and delamination and almost no weight loss. Within these samples, preconsolidation increased the durability of the treated plaster to wet/dry cycling.

bulk specific gravity: The change in bulk specific gravity due to consolidation is so small with all of the consolidants that this property is not a factor in the choice of consolidant. Some consolidants even appeared to reduce the bulk specific gravity of the Çatalhöyük plasters. This may be due to the reaction of solvents such as methyl ethyl ketone and isopropanol with the clays which results in swelling and thus increased volume, or it may simply be due to experimental error.

changes in optical properties: The solvent-based ethyl silicate systems darkened the plaster samples, whereas the ethyl silicate monomer did not. The organic resin consolidants darkened the samples slightly, but almost a negligible amount. Generally, the ground plaster layers were darkened more than the finish plaster. Preconsolidation with the acrylic resin followed by consolidation with the ethyl silicate systems resulted in an unacceptable darkening of the plaster. Thus only the ethyl silicate monomer used alone caused no color change.



Figure 16: Samples after cutting and before consolidation, used to evaluate the effectiveness of an acrylic resin, epoxy resin, and ethyl silicate polymer.



Figure 17: Samples after cutting and before consolidation, used to evaluate the effectiveness of two ethyl silicates, a polymer and monomer, both with and without preconsolidation.

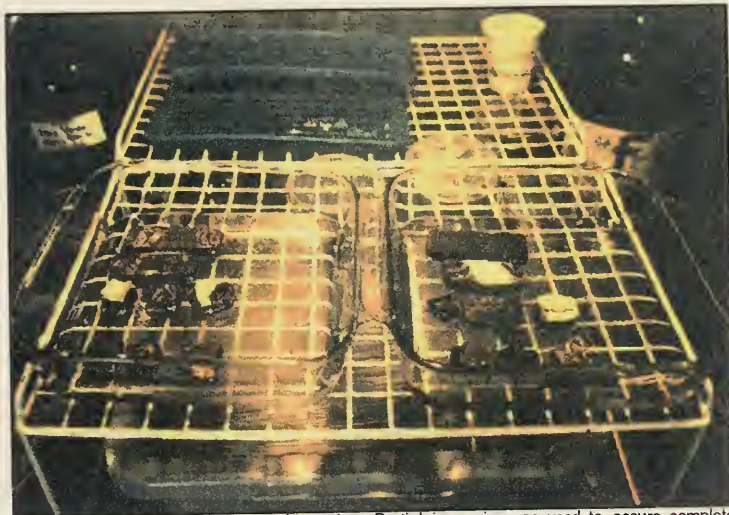


Figure 18: Consolidation by partial immersion. Partial immersion was used to assure complete consolidation and thus comparable test results.

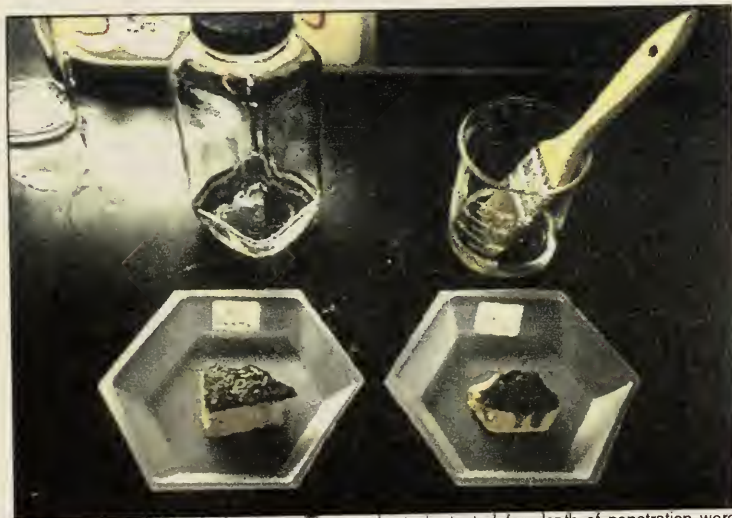


Figure 19: Consolidation by brushing. The samples to be tested for depth of penetration were consolidated by brushing to replicate field application.



Figure 20: Samples after consolidation. The samples were destroyed by some of the consolidants and could thus not be used for modulus of rupture testing as labeled. They were used to measure abrasion resistance instead.



Figure 21: Samples after testing. The samples used to evaluate the increase in resistance to abrasion were put in a chamber and blasted with an abrasive. Each sample was tested three times.

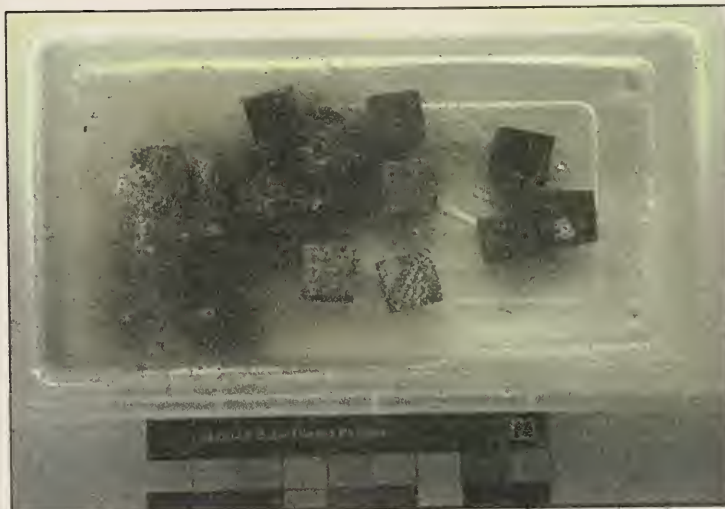


Figure 22: Evaluation of resistance to wet/dry cycling. The unconsolidated samples and some of the consolidated samples, those on the left, deteriorated immediately upon immersion in water.



Figure 23: Evaluation of depth of penetration. The reaction of the iodine vapor with the organic material in the consolidant is visible on the sample on the right.

Chapter Five: Field Testing Program

Because laboratory conditions often represent ideal circumstances which rarely exist in the field, it is necessary to supplement laboratory experimentation with field testing to determine more completely the effectiveness of conservation measures. During August and September of 1996, a series of tests was undertaken on the Çatalhöyük plasters *in situ* under the field direction of Constance Silver and Frank Matero. The purpose of these tests was to determine the methods and materials which would most effectively conserve the plaster in the event of a significant plastered feature, plaster relief, or mural painting being unearthed.

A number of different deterioration mechanisms are acting upon the plasters and each requires a specific treatment. From field testing it is evident that the friable condition of the plasters is one of the major factors affecting the choice of treatments. Consequently, consolidation is one step in the sequence of treatments which will be necessary in order to conserve the plasters, whether they are to remain *in situ* or are to be removed from the site. Although the final sequence and exact materials to be used to conserve the wall plasters, mural paintings, and plaster reliefs of Çatalhöyük is not yet known, significant progress was made during the field testing program toward understanding the interaction of treatments with the plasters.

5.1 Site conditions

During the 1996 field season at Çatalhöyük, excavation took place in three areas of the east mound. In the area previously excavated by James Mellaart in the 1960s, a team of excavators continued to dig in the lower levels of the site with the goal of eventually reaching the earliest levels of occupation. In an area to the north of this, called the North Area, excavation of a building identified during surface scraping of the mound and termed Building 1 proceeded systematically and steadily. A third team worked in the Summit Area on a crest of the mound adjacent to and overlooking the Mellaart Area. These three areas of excavation, each with different objectives, contained architectural features in varying states of preservation allowing for a comparative program of treatment testing.

In the Mellaart Area, the walls of several buildings dating to Mellaart's levels VII and VIII have been unearthed and remain intact. (Figure 24). These are walls composed of mud bricks up to one meter in length and mortar between the bricks. In some cases, the mortar is as thick as the bricks. Based on visual observation, several types of soil have been used to manufacture the mud bricks and mortar. Plaster survives in only a few rooms of the Mellaart Area and is most extensive on the walls of a large open space formed by the joining of two rooms identified as Shrines VII.1 and VII.8 by Mellaart, especially the corner of the south and west walls of Shrine VII.1 and the east wall of Shrine VII.8.

The walls of Building 1 in the North Area are in very good condition, having been recently excavated. Plaster survives on most of the walls of the building, including interior partition walls, from the level of the mound surface to the lowest floor level that has yet been excavated. On the south side of the building, a fire has hardened the mud

brick walls, turning them bright orange, and charred the wall plaster. On the north and west walls of one space in the building, layers of red painted plaster are visible, apparently as part of a dado covering the lower portion of the walls. The excavation in the Summit Area revealed a complete room plan as seen in the scrapped mound surface. Because of the shorter period of excavation in this area, important architectural features and plastered walls were only partially exposed.

Conservation field testing was concentrated in the Mellaart area on fragments of plaster initially exposed during the 1960s with some testing also taking place in the North Building. Although the plaster in the Mellaart Area was protected by earth during the period between the conclusion of the 1960s excavation and the beginning of the current excavations, it was still in a severely eroded condition. Because it represented the worst case scenario of plaster that would be treated, it provided a useful example against which to compare the laboratory experimentation results. In addition, a number of tests were carried out on the more intact plasters of the North Area. This plaster represented conditions likely to be encountered during future excavation and to be treated as part of the conservation program.

Three main conditions of deterioration commonly occur in the exposed plaster of the Mellaart Area: interlayer separation, detachment of the plaster from the mud brick substrate, and loss of intralayer cohesion. Interlayer separation, or delamination, is most obvious on the edges of the plaster fragments which are the least protected from the environment. This delamination is most likely a result of constant swelling and contraction of the clays in the plasters caused by fluctuations in the environment. Detachment of the plaster from the mud brick occurs at the interface between the mud brick and the plaster. In some cases it may be due to the difference in mechanical and

physical properties between the two materials at this interface, and in other cases macrovegetation may cause the separation. The loss of cohesion among the components of the plaster layers is detectable by the weak, friable nature of the plaster. It is a result of the desiccation of the plaster material upon exposure to the dry air. Those areas of plaster which are closest to the ground level, where rising damp provides sufficient but not excessive moisture, are in relatively better condition than areas of plaster which are further from the ground and more exposed to sun. In the more recently exposed areas of the North Area, the loss of intralayer cohesion as well as interlayer separation is also evident, but complete detachment of plaster from the mud brick walls is not yet a major problem.

In addition to the drying out and loss of water within the plasters, excessive water is also detrimental to the plasters. Water causes expansion of the clays within the plasters resulting in tension forces on a microscale and erosion of the plaster surface on a macroscale. The western-facing walls which receive the most wind and precipitation are the most affected by this mechanism of deterioration. The water may also carry solubilized salts which damage the plasters when they crystallize. The crystallization of soluble salts can cause interlayer delamination, complete detachment, and loss of intralayer cohesion.

5.2 Methodology

Although the focus of the laboratory testing program was the assessment of various consolidating systems on the plasters from Çatalhöyük, consolidation was evaluated in conjunction with other treatments in the field testing program. The deteriorated condition of the plasters necessitates a series of interventions which must not adversely affect the plaster itself or limit other treatments. Representative sections of

plaster in the Mellaart Area and the North Area were chosen to evaluate the effectiveness of the various interventions both in isolation and as part of the more comprehensive treatment procedure.

Test sections were selected based on the condition and surface area of the extant plaster present in a given location. The test sections to be used to evaluate preconsolidation and consolidation exhibited a variety of conditions. In the Mellaart Area, sections ranging from 20 cm by 20 cm to 50 cm x 50 cm were chosen for systematic testing of preconsolidants and consolidants. The smaller sections were used for trial testing of preconsolidants. (Figure 25). The larger areas were used to compare preconsolidation with consolidation to simple consolidation and no treatment. (Figures 26 and 27). Two south-facing partition walls in the North Area which had fairly uniform conditions of deterioration were used as well. These walls were exposed during the 1996 field season and were thus only beginning to display the severe delamination and disintegration of the Mellaart Area walls, although one of the walls had been burned and was noticeably darkened.

Delaminated and extremely friable plaster requires preconsolidation as an initial stabilization effort. (Figures 28 and 29). Consolidation generally will not increase the adhesion between plaster layers or between paint layers and plaster. Thus, a preconsolidant which acts as an adhesive is desirable. In addition, plaster in a severely deteriorated state may be too fragile to treat without preconsolidation. Preconsolidation consists of the application of a liquid material onto plaster or other porous material. In the case of the treatment of the Çatalhöyük plasters, the preconsolidant has several functions. The preconsolidant rehydrates the plaster so that delaminating strata can be manipulated during excavation. It also gives some cohesive strength to the plaster so that it is more

durable. In addition, the preconsolidant is an adhesive so that it can be used to reattach paint and flaking layers. After initial stabilization with the preconsolidant, the plaster is then consolidated.

Prior to the evaluation of *in situ* consolidation with preconsolidation, trial tests were carried out to determine the effects of the preconsolidants on the plasters. Two types of preconsolidants were chosen for further testing. These preconsolidants were then tested in conjunction with a consolidant. In each test area, a section in which only the consolidant was applied was used as a control. In the Mellaart area, an adhesive similar to one of the preconsolidants was also used after consolidation to reattach delaminating layers that had not been affixed during preconsolidation.

Grouting was carried out in sections of the Mellaart area where detachment of the plaster from the mud brick wall was the most drastic. (Figure 30). Although grouting was performed simultaneously with preconsolidation, the areas that were grouted were not later consolidated. This was done in order to determine the effectiveness of grouting as a treatment for the plaster and the effects of the grouting materials on the plaster.

Because the walls that will have the highest treatment priority are those walls which possess mural paintings, it was necessary to evaluate the effects of the different treatments on painted plaster. (Figure 31). Thus, three areas of the Mellaart Area with relatively intact plaster were used to investigate the methods and effects of treating painted plaster. Small wall paintings were recreated and a series of treatments were performed on the "painted" sections. These treatments consisted of the application of an isolating material that would protect the paint and plaster from the subsequent consolidation.

5.3 Materials and procedures

Results from the laboratory testing program indicated that the ethyl silicate monomer (T-1919 Conservare® OH Stone Strengtheners) was the most promising consolidant for the treatment of the Çatalhöyük plasters. In addition to providing the greatest depth of penetration with no change in optical properties and appreciable hardening of the plaster, practical considerations favor the monomer. It does not need to be mixed into a solvent and prepared as a solution. The monomer can be applied directly to the plaster and will react with atmospheric moisture to polymerize.¹

Two classes of preconsolidating materials were used in the field testing program: a natural animal glue (rabbit skin glue), and a synthetic polyamine glue (Aquazol® 50). The rabbit skin glue is soluble in water. It is heated before use and becomes tacky upon cooling. The rabbit skin glue was generally prepared as a 5% solution in water (v/v). Aquazol® 50 is soluble in water as well as most alcohols. After the trial tests in the field it was decided that the Aquazol® 50 could not be used as a preconsolidant in any available solvents unless mixed with the consolidant. Aquazol® 50 in ethanol, isopropanol, and water (5% and 10% solutions v/v) followed by consolidation with the ethyl silicate monomer produced extensive blistering, delamination, and weakening of the plasters. A 5% solution of Aquazol® 50 in ethanol (v/v) was prepared and this was then mixed with the consolidant as a 50/50 mixture (by volume). Preliminary testing also indicated that too much of the Aquazol® 50/T1919 Conservare® mixture destroyed the plasters, causing extreme darkening and blistering. Thus, in subsequent field testing, the 50/50 mixture was applied in only one cycle as a preconsolidant.

¹ According to the Product Data and Material Safety Data Sheets for T-1919 Conservare® OH Stone Strengtheners, the monomer will polymerize at “ambient temperatures and atmospheric pressures.”

In the test sections, the rabbit skin glue preconsolidant was brushed onto the plaster through high strength tissue paper. Constant pressure was manually applied to the plaster through the paper to readhere delaminating and flaking plaster. The section pre-treated with the rabbit skin glue was allowed to dry overnight. The Aquazol® 50/T1919 Conservare® mixture was sprayed onto the plaster surface through the paper and pressure applied to the plaster. The consolidant was applied immediately to the section preconsolidated with the mixture. The T1919 consolidant was brushed directly onto the surface of the pre-treated surfaces as well as onto the surface of the control section. Three cycles 30 minutes apart, each consisting of three applications five minutes apart, were applied. The test areas were shaded from direct sunlight for at least two days following treatment.

Several sections of detaching wall plaster were grouted with a phixotropic hydraulic lime/sand grout developed for reattaching lime plaster to adobe walls.² Polyvinyl acetate diluted in water was first injected into the voids between plaster and wall. The polyvinyl acetate acts as a wetting agent so that the mud brick and the plaster do not absorb the water in the grout too rapidly and cause it to crack upon drying. It also is an adhesive which can help to bind together loose material which cannot be removed from the voids. The grout is then injected into the voids where it hardens and reattaches the plaster to the walls.

Replica mural paintings were used to develop a system for protecting paint materials from the plaster conservation treatments. Watercolors, similar to what would have been used to produce the original wall paintings, were applied on relatively intact

² Frank Matero, "A Programme for the Conservation of Architectural Plasters in Earthen Ruins in the American Southwest: Fort Union National Monument, New Mexico, USA," *Conservation and Management of Archaeological Sites* 1, no. 1 (1995).

plaster sections. Rabbit skin glue, the Aquazol® 50/T1919 mixture, and Acryloid® B-72 (5% and 10% in xylene) were used as isolating agents. They were applied with fine watercolor brushes to only the paint itself. The entire plaster section was then consolidated with the T1919 monomer, both without and after preconsolidation.

5.4 Observations

Results from the consolidation and preconsolidation experiments carried out in the field at Çatalhöyük during 1996 are promising but are in no way decisive. The ethyl silicate monomer, when used alone, does not cause any change in optical properties and is able to penetrate at least two centimeters and usually more. Where observable, the monomer penetrated the entire depth of the plaster to the mud brick substrate. It also imparts some hardening to the plaster. However, the increase in hardness, as judged by a simple scratch test, may not be sufficient. This was perhaps due to the inability of the monomer to completely polymerize due to the very low relative humidity in the area.

Because the ethyl silicate monomer did not completely give the desired increase in strength in the field after 30 days, it may be necessary to consolidate the plasters more than once. This may require an initial consolidant which will make the clays in the plaster less reactive so that another consolidant such as Conservare® OH Stone Strengthener can be used. However, because each additional material used in the conservation of the plasters and wall paintings increases the chance of an undesired interaction between treatments, caution should be exercised.

Preconsolidation with rabbit skin glue and the Aquazol® 50/T1919 mixture followed by consolidation produced a significant increase in hardness. However, both preconsolidated sections darkened to an unacceptable level when consolidated. A test area

on the burned wall in the North Area exhibited the greatest darkening, with those areas which were particularly charred being the worst. Trial areas treated only with the preconsolidants were also darkened by the two materials, indicating that the preconsolidants used in the field testing program may be inappropriate in most cases of conserving the Çatalhöyük plasters and wall paintings.

Grouting was most successful when carried out simultaneously with the preconsolidation of the plaster surface. The grouting of voids between plaster and mud brick should not alter the surface appearance of the plaster but may affect the penetration of the consolidant into the mud brick. In addition, grouting will be useless if it only adheres to loose material in the voids and not to two solid faces. Thus, some sort of adhesive which will hold together loose plaster or mud brick material may be necessary prior to injection of the grout.

Experiments done on the newly painted sections of plaster indicate that delicate isolation of the paint material does not always protect the paint from preconsolidation. Areas which were isolated and then preconsolidated with rabbit skin glue and the Aquazol® 50/T1919 mixture tended to smear or loose paint. An isolated area of paint that was only consolidated was almost unchanged.

The results of the field testing program indicate that although preconsolidation will be a necessary first step in the treatment of plastered wall sections, painted walls may have to be treated in a much more detailed manner in order to protect the paint from other conservation treatments. In addition, a preconsolidant which will not change the optical properties of the plaster when followed by consolidation still needs to be identified. Additional treatment following consolidation may also be necessary due to the undramatic results of the T1919 ethyl silicate monomer.



Figure 24: View of the Mellaart Area during the 1996 field season. Excavation is taking place mainly in areas unearthed in the 1960s by James Mellaart.



Figure 25: West wall of Shrine VII.1 showing condition of plaster and location of trial preconsolidation tests.

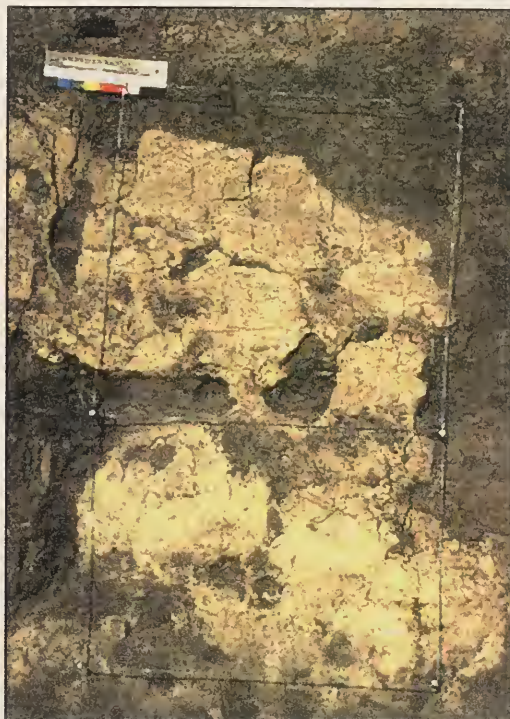


Figure 26: West wall of Shrine VII.1 before preconsolidation and consolidation field testing.



Figure 27: West wall of Shrine VII.1 after preconsolidation and consolidation field testing. The area that has been preconsolidated, the upper rectangle and the right half of the lower rectangle, are slightly discolored.



Figure 28: Test sections on west wall of Shrine VII.1.

Section	Treatment	Results
1	preconsolidant: Aquazol 50/T1919 mixture sprayed in one application consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	slight darkening negligible to slight strengthening of plaster
2	preconsolidant: A-50/T1919 mixture sprayed in one application followed by B-72 (7% in xylene) brushed on consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	significant darkening moderate strengthening of plaster
3	preconsolidant: A-50/T1919 mixture sprayed in one application followed by B-72 (7% in xylene) sprayed on consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	significant darkening moderate strengthening of plaster
4	preconsolidant: A-50/T1919 mixture sprayed in one application followed by Aquazol 50 (5% in ethanol) brushed on consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	significant darkening moderate strengthening of plaster
5	preconsolidant: A-50/T1919 mixture sprayed in one application consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	slight darkening negligible to slight strengthening of plaster
6	preconsolidant: B-72 (7% in xylene) brushed on in one application followed by B-72 (7% in xylene) brushed on consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	significant darkening moderate strengthening of plaster
7	preconsolidant: none consolidant: T1919 sprayed on in 15 cycles over 5 days (3 cycles/day)	no color change negligible to slight strengthening of plaster more loss of detaching plaster than preconsolidated sections

Table 8

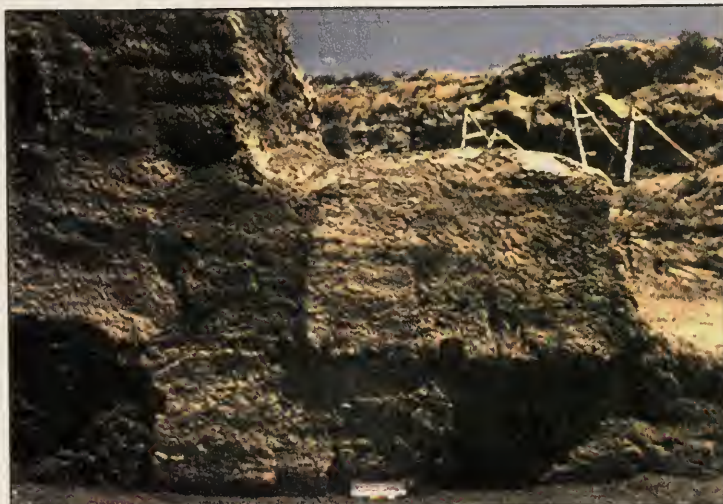


Figure 29: East wall of Shrine VII.8 showing extent of intact plaster and location of trial preconsolidation tests.



Figure 30: Constance Silver applying preconsolidant to the surface of the east wall of Shrine VII.8 in order to stabilize the plaster.

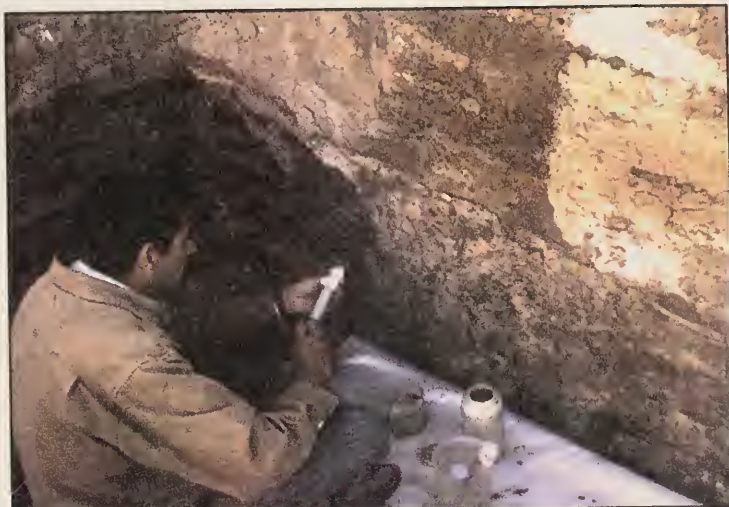


Figure 31: Frank Matero injecting grout behind the lower sections of the east wall of Shrine VII.8 in order to reattach detached pieces of plaster.



Figure 32: Test area painted with watercolors to evaluate the effects of the tested treatments on wall paintings.

Chapter Six: Conclusions and Recommendations

6.1 Conclusions of plaster characterization and analysis

For the purposes of the current study, plaster characterization and analysis were carried out in order to help develop a conservation treatment for the plasters and wall paintings of Çatalhöyük. Any conservation intervention depends on an understanding of the a material and its physical, mechanical, and chemical properties. The plasters from Çatalhöyük provide an invaluable aid to understanding Near Eastern history but present a particularly difficult conservation problem because they display inherent problems due the accumulation of layers and presence of extremely reactive clay minerals.

The wall and relief plasters of Çatalhöyük testify to an important tradition of utilizing locally available materials in the creative and scientific process of constructing the space and world occupied by the inhabitants of the ancient settlement. The wall plasters of Çatalhöyük were applied as a two coat system using marl or soft lime soils which would have been readily available and relatively simple to process. The presence of numerous intact shells in the plaster lays and the plentiful quantity of easily-manipulated marl soils in the area support the likelihood of the plasters being earthen rather than true burnt lime plasters, although the technology to calcine and slake lime may have existed at the site. Each sequence consists of a light brown ground plaster layer and a white finish layer. Wall plasters may contain over 80 sequences of these two coats, usually on a single preparatory layer, indicating frequent replastering. In addition, the ground layers are often less than 0.5 mm and the finish coat is usually half of the thickness of the ground layer. The finish coat contains almost no medium- and coarse-sized particles. The soils were probably mixed with water, perhaps after some type of levigation or sieving, and applied as a slurry. The principle components of each layer are fine calcite particles held in a clay matrix. Quartz, feldspars, and unburned shell fragments are

typical inclusions. The microfabric and structure of the plaster layers remain remarkably consistent from the earliest sequence in a sample to the latest. The relief plasters consist mainly of the same type of marl soil used as a ground coat for the wall plasters, but the plaster is molded and sometimes painted. When painted, there is usually an underlying finish plaster layer.

Because they are earthen plasters and not fired lime or gypsum, the plasters depend partly on moisture to bind together the component materials. When exposed during excavation, the plasters lose whatever moisture they retained when insulated by the earth and the clay, calcite, and quartz minerals lose their intergranular cohesion. The dominant clay type is smectite which is extremely reactive to water and other liquids. Because smectite swells when it comes into contact with water, the plasters delaminate between layers. In addition, many of the materials most often used in conservation would cause more damage than good to the plasters, making conservation more complicated.

6.2 Recommendations for consolidation as part of a comprehensive conservation program

The plasters and wall paintings from Çatalhöyük not only play an extremely important role in the interpretation and understanding of the settlement, but they also form part of the technological and artistic history of the Near East. The identification of materials and processes used in the manufacture and application of plaster contribute to an understanding of industry and technology at Çatalhöyük. The decorative and symbolic roles that the plasters and wall paintings present as part of the architectural context are one

of the most important features of the site. Thus, the plasters are an integral component of the site and worthy of conservation.

Depending on the archaeological and interpretive value of an excavated section of wall and plaster, different levels of conservation may be applied. In cases where only the information from a feature is important, only documentation of the wall and plaster may be appropriate. In other cases, such as the discovery of isolated mural fragments, lifting of the painted plaster by *strappo* or *stacco* techniques can be accomplished without the removal of the mud brick wall. Ultimately, some of the walls possessing painted plaster surfaces will be removed from the site *in toto* by a method of detachment, lifting, and relocation.

The rapid rate of desiccation which takes place within the plaster materials once they are subjected to normal exterior conditions will necessitate the use of a preconsolidant to stabilize the exposed surface in most cases. There are several advantages to the use of a preconsolidant: it is a quick and simple procedure, it imparts additional hardening to the plaster and protection to paint surfaces, and it stabilizes the plaster more immediately than most consolidants which may take several days to cure. The disadvantage to using a preconsolidant is that it must be compatible with the plaster and the consolidant. Additional reattachment of flaking plaster layers or paint layers by means of microinjection may also be necessary.

Once the plaster has been preconsolidated, subsequent treatments will depend on the value of the feature and its ultimate role in the interpretation of Çatalhöyük. If preservation of the feature is not necessary, it will be completely recorded and then destroyed following normal excavation procedures. In the event that a mural fragment is to be removed without the mud brick substrate, a means of facing the plaster surface with

a removable fabric must be devised. The adhesive used to attach the facing to the plaster must not interfere with the other treatments or alter the appearance of the plaster. The paint of the mural may also need to be reattached *in situ*, by means of an adhesive.

Those wall features with intact plaster and paintings which are to be removed from the site for further examination or conservation will require complete consolidation of the plasters. The mud brick is in excellent condition, being very cohesive and intact in most areas and hardened by burning in other areas. The most prevalent mechanism of plaster deterioration at Çatalhöyük is the desiccation of the components within the plaster leading to powdering and flaking of the plaster surface and interior. Consolidation is therefore necessary to impart additional cohesive strength and hardening to the plasters. Consolidation can be undertaken immediately after preconsolidation but will take several days to be effective. Other types of treatments may be necessary depending on the condition of the plaster. Grouting can be carried out in those areas in which the plaster has detached from the mud brick walls, leaving sizable voids. Grouting, by means of injection can be done either before or after consolidation. It is perhaps best done in conjunction with other preconsolidation treatments. After consolidation, the plaster surface should be faced to protect it. As with facing mural fragments removed by strappo or stacco, the facing procedure should not alter the appearance of the plaster or react with the consolidant. The wall feature can then be boxed and polyurethane foam injected into the box to cushion and distribute more evenly the forces exerted on the wall as it is lifted and removed.

6.3 Recommendations for further research

Because the characterization and analysis of the plasters from Çatalhöyük were undertaken as a means of understanding the treatment of the plasters and the research focused on a single treatment of the plasters, namely consolidation, many avenues of inquiry and trails of discovery were left untraveled. Future research is necessary both to assist the archaeologists who will ultimately interpret the site and the conservators who will be charged with conserving it.

There remain many unanswered questions about the source of plaster materials and methods of production which can ultimately be valuable to the reconstruction of the economy and industry of Çatalhöyük. Some of these are archaeometric questions, such as the geographical relationship between the two sources of soil used in the wall plaster, if two types of soil were used. X-ray diffraction of the plaster is currently being conducted by Jackie Frizano in order to identify the clay species present in the wall plasters. Identifying the types of materials which are present in the plasters is critical to understanding production as well as treatment of the plasters. Richard Wolbers of Wintethur has conducted analysis of organic material in the wall plasters and concluded that just as there is a repeating pattern of ground and finish plaster, natural plant resins occur in a regular pattern between each sequence. In addition, there may be a proteinaceous binder in the finish plaster. More analytical and archaeological research would help to illuminate some of these findings. Another important line of research, is the location of plaster manufacture within the site. It would be useful to the understanding of the site to identify the areas where plaster production took place, if there is a specialized area. The relation between plaster and mud brick sources and production is also a topic that would be very worthy of future research.

At the end of the field season, 25 plaster samples were removed from the walls of the North Building for examination in the laboratories on site. This initial attempt at microscopic analysis of plasters in the field proved to be very promising. Questions concerning the sequence of events and symbolic importance of material culture could be examined using scientific tools of analysis. Field methods for the analysis of the plasters and other architectural material and the use of plaster as an archaeological tool of reconstruction are thus two additional lines of future research.

Observations made during the field testing program raise more questions about the materials and methods of treatment. Although the ethyl silicate monomer provided some initial hardening of the plasters in the field, they did not strengthen the plaster to the desired level, perhaps due to incomplete polymerization. The effects of low relative humidity on the polymerization of the ethyl silicate monomer need to be studied in a controlled laboratory environment. In addition, the darkening of the plasters after preconsolidation and consolidation is most likely due to the choice of preconsolidant, based on the test areas used as controls. A laboratory testing program devised to assess methodologically the effectiveness of preconsolidation followed by consolidation is necessary.

It is hoped that through continued analysis and experimentation both in the laboratory and the field, many of the questions that still remain unanswered will become clearer. One of the benefits of working on a site as large as Çatalhöyük is that there are many researchers and specialists involved in a variety of productive studies. It is an invaluable opportunity for collaboration between these specialists to address the complex issues of field conservation of architectural remains in archaeological sites.

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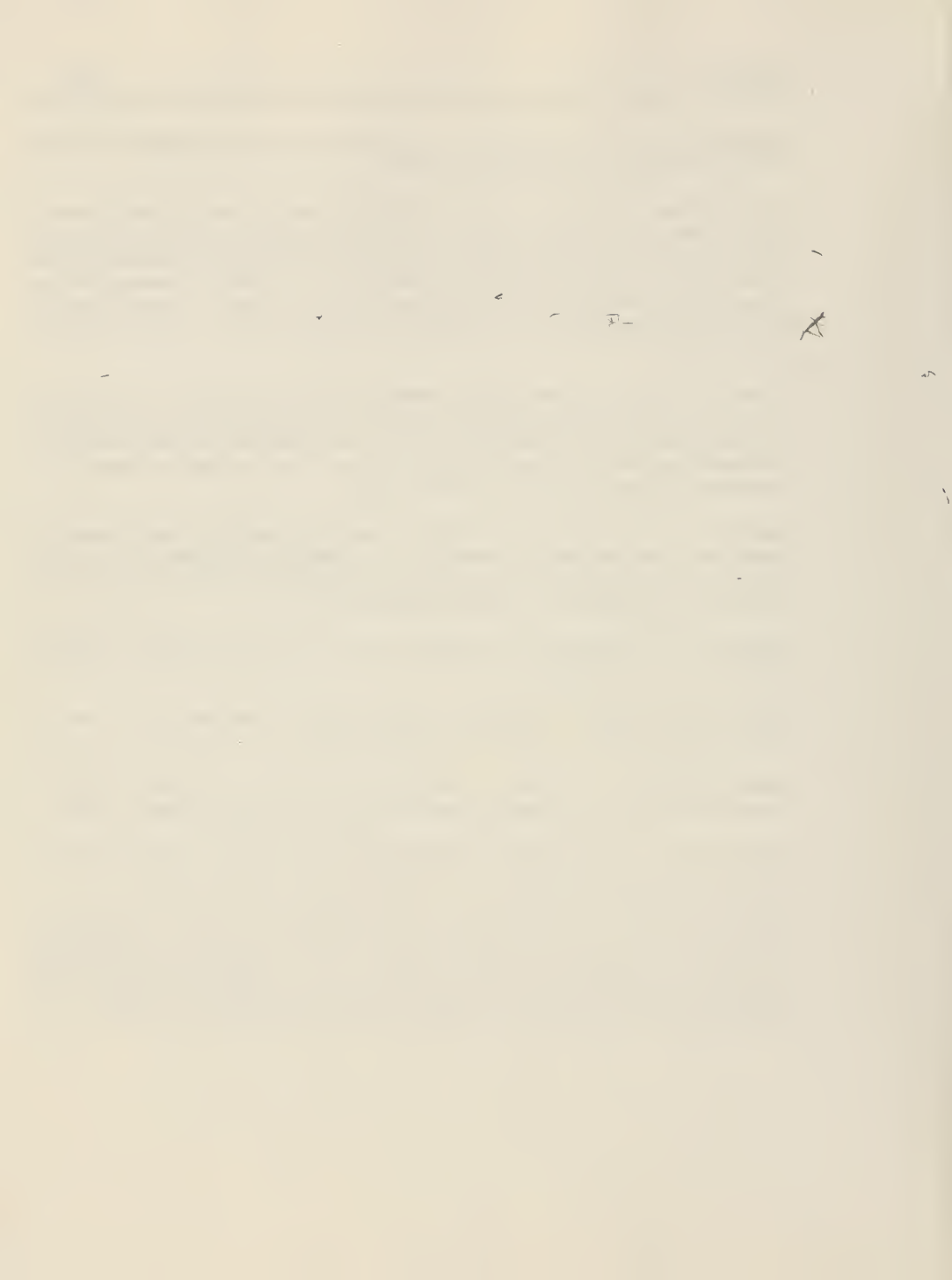
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Appendix A: Recent Plaster Characterization and Analysis Case Studies

Aslam, M. "Studies on Taj Mahal Plasters." *Studies in Conservation* 35 (1990): 102-106. ✓

Project Site(s): Taj Mahal, India

Principle Research Questions: mechanisms of deterioration acting upon the lime plaster, composition of the plaster

Analytical Techniques Used: granulometric analysis, chemical analysis, x-ray diffraction, infrared analysis, thin section petrography, scanning electron microscopy

Comments: A range of complementing techniques were used to determine the composition of the lime plasters and give some indication of its deterioration.

Boulton, Ann. "Some Considerations in the Treatment of Archaeological Plaster Figures ✓
from 'Ain Ghazal, Jordan." In *The American Institute for Conservation of Historic and Artistic Works. Preprints of Papers Presented at the Sixteenth Annual Meeting, New Orleans, Louisiana, June 1-5, 1988*, edited by Sarah Z. Rosenberg, 38-57. Washington, DC: The American Institute for Conservation of Historic and Artistic Works, 1988.

Project Site(s): 'Ain Ghazal, Jordan (ca. 6,000 BC)

Principle Research Questions: method of manufacture, source of material

Analytical Techniques Used: chemical analysis, x-ray diffraction, scanning electron microscopy with energy dispersive x-ray analysis

Comments: SEM used to compare morphology to samples of known material, and thus identify components in the plaster

Brown, Gordon E. "Testing of Concretes, Mortars, Plasters, and Stuccos." *Archeomaterials* 4 (1990): 185-191. ✓

Project Site(s): Roman harbor (ca. first century BC); Palenque, Mexico (ca. 700-750 AD); Kohunlich, Mexico (ca. 100-300 AD, ca. 600-900 AD); Ontario, Canada (nineteenth century)

Principle Research Questions: physical and chemical properties of concretes, mortars, plasters, and stuccoes, provenience of materials

Analytical Techniques Used: tests for unit weight, absorption, compressive strength, Mohs hardness, lime content, carbonation, aggregate extraction, optical microscopy

Comments: simple, standardized tests used to provide basic characterization

Goren, Yuval and Paul Goldberg. "Petrographic Thin Sections and the Development of Neolithic Plaster Production in Northern Israel." *Journal of Field Archaeology* 18, no. 1 (spring 1991): 131-137. ✓

Project Site(s): northern Israel (8,000-4,000 BC)

Principle Research Questions: method of manufacture

Analytical Techniques Used: optical microscopy, thin section petrography

Comments: thin section petrography was shown to have tremendous value in the study of plaster materials

Gourdin, William Hugh. "A Study of Neolithic Plaster Materials from the Near and Middle East." Master's thesis, Massachusetts Institute of Technology, 1974. ✓

Project Site(s): Neolithic Middle East (ca. 7,000-5,900 BC); Timna, Israel (ca. 1,400-1200 BC)

Principle Research Questions: method of manufacture, geographical distribution of pyrotechnology

Analytical Techniques Used: optical microscopy, thin section petrography, thermoluminescence, chemical analysis, differential thermal analysis

Comments: a variety of features were examined in order to classify them as calcined gypsum or lime

Gourdin, W. H. and Kingery, W. D. "The Beginnings of Pyrotechnology: Neolithic and Egyptian Lime Plaster." *Journal of Field Archaeology* 2, no. 1/2 (1975): 133-150. ✓

Project Site(s): Neolithic Middle East (ca. 7,000-6,300 BC); Timna, Israel (ca. 1,400-1,200 BC)

Principle Research Questions: method of manufacture, geographical distribution of pyrotechnology

Analytical Techniques Used: optical microscopy, x-ray dispersive analysis, x-ray diffraction, differential thermal analysis, spectrochemical analysis, wet chemical analysis

Comments: plasters were examined to determine whether they were earthen, gypsum, or lime

Karant, R. V., K. Krishnan, and K. T. M. Hedge. "Petrography of Ancient Indian Lime Plaster." *Journal of Archaeological Science* 13, no. 6 (November 1986): 543-551. ✓

Project Site(s): Kavan, India (seventh century AD)

Principle Research Questions: composition of plasters, provenience of materials, skill of plasterer, and technological ability of culture

Analytical Techniques Used: optical microscopy (reflected and transmitted light), wet chemical analysis

Comments: simple techniques were used as part of a larger program of archaeological research to answer complex social questions

Kingery, W. David, Pamela B. Vandiver, and Martha Prickett. "The Beginnings of Pyrotechnology, Part II: Production and Use of Lime and Gypsum Plaster in the Pre-Pottery Neolithic Near East." *Journal of Field Archaeology* 15, no. 2 (summer 1986): 219-244.

Project Site(s): Neolithic Near East (ca. 7,200-6,000 BC)

Principle Research Questions: method of manufacture, geographical distribution of pyrotechnology

Analytical Techniques Used: optical microscopy, x-ray dispersive analysis, x-ray diffraction, differential thermal analysis, spectrochemical analysis, wet chemical analysis

Comments: this study expands upon the earlier work of Gourdin and Kingery and includes analysis of samples from more sites

Kingery, W. David, Pamela B. Vandiver, and Tamar Noy. "An 8,500-Year-Old Sculpted Plaster Head from Jericho (Israel)." *MRS Bulletin* 17, no. 1 (January 1992): 46-52. ✓

Project Site(s): Jericho, Israel (ca. 6,500 BC)

Principle Research Questions: method of manufacture, cultural associations

Analytical Techniques Used: radiography, optical microscopy, x-ray diffraction, scanning electron microscopy with energy dispersive x-ray analysis

Comments: instrumental analytical techniques were used to determine the materials of an artifact and its manufacture process in order to establish cultural connections

Klemm, D. D. and R. Klemm. "Mortar Evolution in the Old Kingdom of Egypt." In *Archaeometry '90: International Symposium on Archaeometry, 2-6 April 1990, Heidelberg, Germany*, edited by Ernst Pernicka and Günther A. Wagner, 445-454. Basel: Birkhäuser Verlag, 1991. ✓

Project Site(s): Old Kingdom Egypt (ca. 2,650 BC)

Principle Research Questions: method of manufacture, development of gypsum and lime plaster technology

Analytical Techniques Used: thin section petrography, x-ray diffraction

Comments: thin section petrography was found to be the most useful method for determining the nature of the plasters

Magaloni, Diana et al. "Electron Microscopy Studies of the Chronological Sequences of Teotihuacán Plaster Technique." In *Materials Issues in Art and Archaeology III: Symposium held April 27-May 1, 1992, San Francisco, California, U. S. A.* Materials Research Society Symposium Proceedings, Vol. 267, edited by Pamela B. Vandiver, James R. Druzik, George Segal Wheeler, and Ian C. Freestone, 997-1005. Pittsburgh: Materials Research Society, 1992.

Project Site(s): Teotihuacán, Mexico

Principle Research Questions: development of plaster manufacturing techniques

Analytical Techniques Used: optical microscopy, scanning electron microscopy, x-ray diffraction

Comments: analysis of plaster is included as part of the overall archaeological research to determine the development of the site

Newton, R. G. and J. H. Sharp. "An Investigation of the Chemical Constituents of Some Renaissance Plasters." *Studies in Conservation* 32 (1987): 163-175.

Project Site(s): Northwestern England houses (sixteenth to seventeenth century AD)

Principle Research Questions: identity of plasterers and design features, source of material, composition of plasters, method of manufacture

Analytical Techniques Used: x-ray diffraction, differential thermal analysis, chemical spot tests, atomic absorption spectroscopy, thermogravimetry, electron probe micro-analysis, scanning electron microscopy

Comments: the series of tests were used to divide the plasters into general groups based mainly on composition

Rao, N. Rama and K. Maruthi Prasad. "Studies on Some Lime Plasters." *Journal of Archaeological Chemistry* 3 (December 1985): 13-20. *Red Found*

Project Site(s): Vaddamanu, India (ca. 200 BC-300 AD)

Principle Research Questions: ratio of calcium oxide to silica

Analytical Techniques Used: wet chemical analysis

Comments: the calcium oxide:silica ratio was used to determine whether the plasters are lime or earthen

Tubb, K. W. "Conservation of the Lime Plaster Statues of 'Ain Ghazal." In *Recent Advances in the Conservation and Analysis of Artifacts*, compiled by James Black, 387-391. London: Summer Schools Press, 1987.

Project Site(s): 'Ain Ghazal, Jordan (ca. 6,000 BC)

Principle Research Questions: method of manufacture

Analytical Techniques Used: x-ray diffraction, scanning electron microscopy with energy dispersive x-ray analysis

Comments: analysis follows techniques used by Gourdin and Kingery

Appendix B: List of Samples Supplied to the Architectural Conservation Laboratory

The samples used by the Architectural Conservation Laboratory (ACL) of the University of Pennsylvania for the characterization and treatment assessment of architectural plasters from Çatalhöyük were removed from the site during the summers of 1994 and 1995.

Two boxes containing four plaster samples were sent to the ACL following the 1994 season of excavation. The descriptions of these four samples are those of Dr. Wendy Matthews of the McDonald Institute for Archaeological Research, Cambridge, England as written in a letter to Professor Frank G. Matero

Sample no. 94.18: Wall plaster adhering to mud bricks and mortar. Cut out as a block 20 x 13 cm, 7 cm thick, from the southern end of the eroding section of Area E of the 1960s excavations (1994 field section number 7.3). The wall plaster was facing east into an unexcavated room and was still adhering to mud bricks and mortar which were eroding from the section face. Collected on 21 September 1994.

Sample no. 94.19: Multiple layers of white wall plaster. This block 14 x 16 x 5 cm was found in the slope wash at the base of the northern wall of Area E building 47 (1993 field section number 5, facing S). Collected on 19 September 1993. After wrapping in tissue and tape and air drying it was stored for one year in a wooden crate in the locked storeroom in the expedition house in Çumra before export.

Sample no. 94.17: Wall plaster adhering to mud bricks and mortar. This block 27 x 13 x 5 cm was found in slope wash at the base of the large east section in Area E (1994 field section no. 7) on 15 September 1994.

Sample no. 94.20: Multiple layers of white wall plaster. This block 12 x 12x 4 cm was found in slope wash at the base of the large east section in Area E (1994 field season no. 7) on 29 September 1994. After wrapping in tissue and tape and air drying it was stored for one year in a wooden crate in the locked storeroom in the expedition house in Çumra before export.

The mud brick attached to sample numbers 94.17 and 94.18 were both used in the current study for the preliminary determination of bulk specific gravity. The plaster of sample numbers 94.19 and 94.20 were used in the laboratory testing program.

In addition to these four samples, two large wooden boxes containing 18 plaster fragments were exported from Turkey after the 1994 field season. These samples were mostly wall plasters. The sample numbers and descriptions given below are translations provided by Evin Erder of the list approved by Turkish Ministry of Culture for export.

Sample no.	Size in cm.	Section no.	Plaster type	Use in current study
2	9 x 7 x 15	6	room floors and fillers	
3	10 x 8 x 14	6	oven floors	
4	10 x 7 x 14	6	room floors and fillers	
5	10 x 8 x 13	6	room floors and fillers	
6	4 x 15 x 7	6	room floors and fillers	
7	6 x 5.5 x 8	6	room floors and fillers	
8	4 x 5 x 8	6	room floors and fillers	
9	13 x 13 x 9	6	oven floors	

Sample no.	Size in cm.	Section no.	Plaster type	Use in current study
10	11 x 8 x 14	6	open area fillers	Sample C used as bulk sample, cross section, thin section, SEM, and wet chemical analysis. Preliminary determination of bulk specific gravity. Laboratory Testing Program.
11	12 x 8 x 15	6	open area fillers	Sample A used as bulk sample, cross section, thin section, SEM, XRD, and wet chemical analysis. Laboratory Testing Program
12	9 x 8 x 10	6	room floors and fillers	Laboratory Testing Program
13	9 x 7 x 14	6	mud brick and mortar	Preliminary determination of bulk specific gravity. Preliminary assessment of consolidation treatments.
14	12 x 10 x 15	6	mud brick and mortar	
15	9 x 8 x 15	7	room floors and fillers	Laboratory Testing Program
16	10 x 6.5 x 14	7	room floors and fillers	
17	27 x 5 x 13	7	mud brick and plaster	Preliminary determination of bulk specific gravity
18	20 x 13 x 7	7	mud brick and plaster	
19	14 x 5 x 16	7	plaster (relief plaster)	Preliminary determination of bulk specific gravity.

Table 9

Accompanying the above samples were two small painted plaster samples labeled “sheena wall black” and “Ch 95 Mell 1014 5/9 8F” and small fragments of red painted plaster. These three sample groups were examined by Catherine Turton in the assessment of mural painting conservation. Another large relief plaster sample, labeled “1154 113” was used for the preliminary determination of bulk specific gravity and wet chemical analysis.

Another group of unprovenienced samples was also included in the characterization and consolidation of Çatalhöyük plasters. These samples included the following:

- Three mud brick samples, one of which was labeled Sample D and used for bulk sample examination, cross section characterization, thin section micromorphology, SEM, wet chemical analysis, and the preliminary determination of bulk specific gravity.
- Three crumbling plaster fragments, one of which were used for the preliminary assessment of consolidation treatments.
- One relief plaster sample with painted layers, labeled Sample B and used for bulk sample examination, cross section characterization, thin section micromorphology, SEM, XRD, wet chemical analysis, and the preliminary determination of bulk specific gravity.

Appendix C: Descriptions and Photomicrographs of Cross Sections and Thin Sections

CROSS SECTION EXAMINATION		SAMPLE A ₁
Sample Location: Section 6, Çatalhöyük, Turkey		
Substrate: mud brick (not present in sample)	Finish: ground and finish plaster	Number of Layers: 154
<p>General Description:</p> <p>The sample consists of a preparatory plaster layer 1-3 mm thick and alternating layers of ground and finish plaster. There is no dirt accumulation between the plaster layers, but some bending of the layers and morphological disturbance within the plaster. The ground plaster is the same light brown color as the preparatory layer (2.5Y 8.5/2) and the layers are generally about 0.100 to 0.500 mm thick. The finish plaster appears off-white in the cross section. These finish layers are almost always thinner than the ground plaster, usually half as thick as the adjacent ground plaster layers.</p> <p>The first layer is a brown preparatory coat which has long thin voids running parallel to the plaster layers above. Inclusions in the preparatory layer include black angular particles which may be charcoal, smaller subangular, subround, and round particles of various colors (black, red, orange, white, clear).</p> <p>The layers above the preparatory layer can be classified into at least two types based on color, compactness, and the amount of inclusions: a brown ground plaster and a white finish plaster. The ground layers are the same color as the preparatory coat and the thicker examples have voids and mineral particles similar to the long thin voids and inclusions in the preparatory coat. One of the voids appears to have organic fibers in it. Most of the ground layers are thicker than the finish layers adjacent to them. The finish plaster appears denser than the ground or preparatory layers with less voids and nearly no coarse particle inclusions. Both the ground layers and finish layers tend to have very even and continuous top and bottom surfaces.</p>		

Above two of the finish layers near the top of the sample are another type of plaster which may be a type of ground plaster. It is a slightly lighter brown than the ground plaster layers which immediately follow it. There is no accumulation of dirt or soot between any of the plaster layers.

The first 114 layers in the sample have been distorted somewhat so that they are bent or curved. Sometimes this distortion occurs near a crack or void, but in some cases, as with the first 14 layers, there does not appear to be any physical interference which would cause the bending. The cracks that occur within the sample are generally parallel to the plaster layers and occur more often in the finish layers than between a ground and finish layer or in the ground layer. The last 40 layers are very straight and parallel to each other.

THIN SECTION EXAMINATION		SAMPLE A ₂
Sample Location: Section 6, Çatalhöyük, Turkey		
Substrate: mud brick (not present in sample)	Finish: ground and finish plaster	Number of Layers: 154
<p>General Description:</p> <p>The sample consists of a preparatory layer and many thinner layers which alternate between two types of plaster. The preparatory layer is the thickest layer in the sample. The plaster layers are of two distinct types, perhaps from two different sources. Each layer of the plaster tends to be fairly compact and homogenous in composition and thickness, but there are differences between layers. The plaster layers curve near the center of the sample, becoming gradually more round as one moves away from the substrate and then leveling off near the top of the sample. There are also cracks and separations between some of the plaster layers. On a micromorphological level, the plaster has an intergrain channel structure, meaning that the dominant voids are channels which disrupt the continuity of the closely packed mineral grains. There are few aggregates in any of the plaster layers.</p> <p>The preparatory layer consists mainly of fine-sized particles. It stains yellow with sodium cobalt nitrate, indicating a high amount of potassium feldspar. The percentage of medium- to coarse-sized particles does not exceed 5% and is closer to 2% to 3%. The medium- and coarse-sized constituents are almost exclusively quartz and plagioclase feldspar. There are also large pieces of mineralized charcoal wood in the preparatory layer.</p>		

The multiple plaster layers on top of the preparatory layer can be considered of two types, based on the binding material. The first type, which tends to be thicker than the other, consists primarily of fine-sized particles which stain positive for calcite in the presence of alizarin red S. The percentage of medium and coarse constituents ranges from 0% to 1%. As with the preparatory layer, these are mainly quartz and feldspar. The second type is a finish plaster which is mainly fine-size particles that stain positive for calcite in some cases and in other cases do not. It contains less medium and coarse particles, although it does contain some. In general, there is a sharp zone of contact in between the two types of plaster.

Although mainly fine-sized particles with a very small percentage of quartz and feldspar coarse constituents, the sample contains some uncharacteristic components. Just below layer 79 there is a large crack which runs across the entire sample. Below this crack is a layer of ground plaster containing a great deal of coarse particles. These quartz and feldspar particles are roughly 20% of the layer. They may represent a patched area, and may be one of the causes of the separation of the plaster layer directly above it. However, the area adjacent to another large crack between layers does not possess this uncharacteristically high amount of medium and coarse particles. Another important feature of the sample is the presence of a curved, mineralized fragment in a layer of finish plaster. This component may be either shell or fibrous organic material. If the former is the case, it may indicate that the plaster material is not calcined lime. Shells would have been deformed during the firing stage of plaster production.

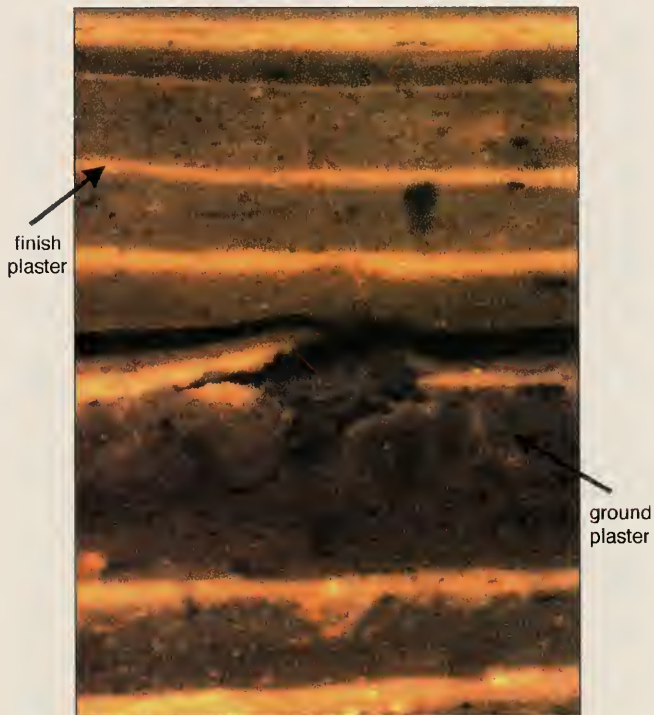


Figure 33: Photomicrograph of cross section A1 showing typical plaster layers and crack along the layers. 62.5x magnification under reflected quartz halogen illumination.

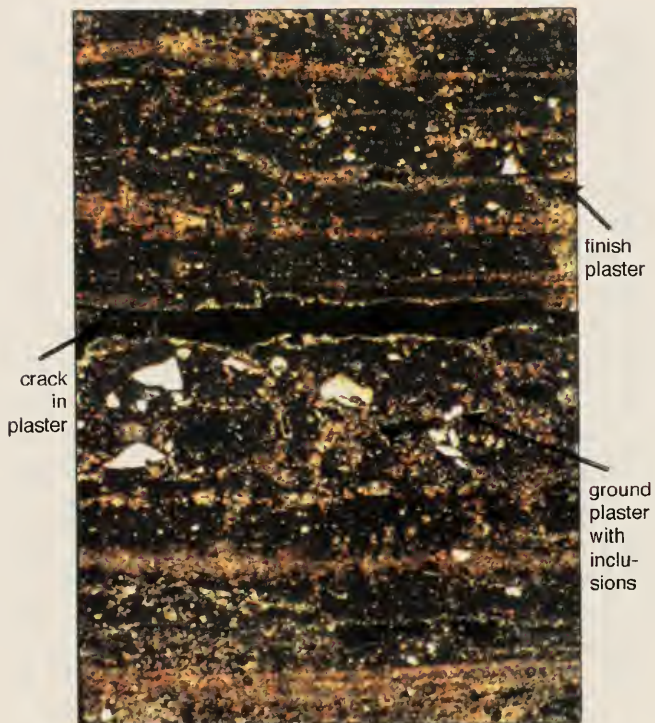


Figure 34: Photomicrograph of thin section A2 showing coarse-sized mineral inclusions in ground layer under crack. 50x magnification under transmitted cross-polarized light.

CROSS SECTION EXAMINATION		SAMPLE B ₁
Sample Location: unknown location, Çatalhöyük, Turkey		
Substrate: packing plaster	Finish: ground and finish plaster, paint	Number of Layers: varies within the sample
<p>General Description:</p> <p>The majority of the sample is made up of packing plaster which is molded to have a rounded shape at one end. The thin voids in the packing plaster follow the contour of this rounded shape. The inclusions in the packing plaster include subangular, subround, and round particles of the following colors: Black, red, orange, white, and clear. Some of the white inclusions which are long, thin, and curved appear to be fragments of shell. There is some cracking in the packing plaster which does not follow any characteristic pattern of orientation.</p> <p>The stratigraphy of the subsequent plaster and paint layers is not consistent on the different sides of the sample. However, both sides show certain similarities. There are two distinct paint layers around the entire sample. The ground plaster layers tend to have fewer and smaller inclusions than the packing plaster, although the two types of plaster are similar in color and texture. Also, dirt and soot has accumulated between most of the ground plaster layers. The layers of ground plaster are generally from 0.25 to 1 mm thick.</p>		

THIN SECTION EXAMINATION		SAMPLE B ₂
Sample Location: unknown location, Çatalhöyük, Turkey		
Substrate: packing plaster	Finish: ground and finish plaster, paint	Number of Layers: varies within the sample
<p>General Description:</p> <p>The bulk of the thin section is a mass of compacted packing plaster consisting mainly of fine particles with roughly 0% to 2% medium- and coarse-size quartz and feldspar particles. This plaster has been molded into a curved or rounded shape which can be discerned by the orientation of long, thin voids left by the disintegration of organic material used to strengthen the plaster. Overall the sample has a channel structure with some notable chamber voids. There are also long and thin biomorphic fragments surviving within the compacted plaster which are probably shell, based on their shape and strongly positive staining for calcite.</p> <p>Around the edge of the rounded sample are several thin layers of finish plaster. These layers are curved around the packing plaster. The ground layers and intermediate dirt and soot accumulations cannot be differentiated in thin section. The fact that there appears to be no compositional difference between the ground layers indicates that they may contain material taken from the same source. There are two layers of red paint visible in the sample. Associated with these painted layers are several gypsum crystals.</p>		

Stratigraphy:

On one side of the sample (the right side when the curved end points to the top), the area with the most complete stratigraphy has the following sequence of layers:

layer	type of layer	description of layer
1	packing plaster	inconsistent positive stains for calcite, positive stains for potassium feldspar; voids along contour lines of subsequent layers; coarse fraction not above 5%, some shell fragments
	dirt/soot	
2	ground plaster	2 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
3	ground plaster	1-2 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
4	ground plaster	2 mm; similar texture, voids, and inclusions as packing plaster; slightly lighter brown than packing plaster
5	finish plaster	0.050 mm; white; uneven bottom surface, even top surface; no inclusions; does not run around the entire contour of the sample
	dirt/soot	
6	ground plaster	0.01-0.5 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
7	paint	0.050-0.50 mm; reddish orange; uneven top and bottom surfaces; some subangular black and clear particles; crack down the center of part of the paint layer
8	ground plaster	1 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
9	paint	0.050-0.25 mm; reddish orange; uneven top and bottom surfaces; not as many black and clear particles as previous paint layer
	dirt/soot	
10	ground plaster	0.25-0.50 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster, including a white shell-like fragment
11	ground plaster	0.25-0.50 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	

12	ground plaster	0.25-0.50 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
13	ground plaster	0.25-0.50 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
14	ground plaster	0.25 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
15	ground plaster	0.50 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster; crack running down part of the layer
	dirt/soot	thicker and blacker than most dirt/soot layers in sample
16	ground plaster	0.25 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
17	ground plaster	1 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
18	ground plaster	0.050 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	soot is concentrated in one area of the layer
19	ground plaster	1-2 mm; similar color, texture, voids, and inclusions as packing plaster, including a large angular clear fragment (quartz)
	dirt/soot	
20	ground plaster	0.25 mm (sample is broken off before layer ends); slightly lighter brown than packing plaster; similar texture, voids, and inclusions as packing plaster

On the opposite side of the sample (the left side when the curved end points to the top), the most complete stratigraphy contains 28 layers of plaster and paint. Thirteen of these are on a fragment which has separated from the bulk of the sample:

layer	type of layer	description of layer
1	packing plaster	inconsistent positive stains for calcite, positive stains for potassium feldspar; voids along contour lines of subsequent layers; coarse fraction not above 5%, some shell fragments
2	paint	0.050-0.25 mm; reddish orange; uneven top and bottom surfaces; microcrack running down center of part of the paint layer
3	ground plaster	0.10-0.50 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
4	ground plaster	0.025 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
5		0.025 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
6	ground plaster	0.025 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
7	ground plaster	0.050 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
8	finish plaster	0.025 mm; white; disturbed by subangular clear particles in some areas, but generally has no inclusions and voids; uneven bottom surface, more even top surface
9	ground plaster	0.025 mm; slightly darker brown than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
10	ground plaster	0.025-1.5 mm, generally about 1 mm; similar color, texture, voids, and inclusions as packing plaster, including a shell-like fragment

11	finish plaster	0.025 mm; generally has no inclusions and voids; extremely uneven bottom surface with some plaster seeping into cracks in ground plaster below, more even top surface
12	paint	0.025-0.50 mm; reddish orange, but less saturated than other paint layers; uneven top surface, more even bottom surface
13	ground plaster	1-1.5 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
14	ground plaster	0.50-0.75 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
15	ground plaster	0.25 mm then fracture; similar color, texture, voids, and inclusions as packing plaster
	fracture	
16	ground plaster	0.75 mm; similar color, texture, voids, and inclusions as packing plaster; some orange paint particle inclusions
	dirt/soot	
17	ground plaster	0.75-1 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
18	ground plaster	1 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
19	ground plaster	0.50 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
20	ground plaster	1 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
21	ground plaster	0.25-0.50 mm; slightly darker than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
22	ground plaster	0.50-1 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
23	ground plaster	0.25-0.50 mm; slightly darker than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
24	ground plaster	0.50-1 mm; similar color, texture, voids, and inclusions as packing plaster

	dirt/soot	
25	ground plaster	0.75 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
26	ground plaster	0.25 mm; slightly darker than packing plaster; similar texture, voids, and inclusions as packing plaster
	dirt/soot	
27	ground plaster	0.75 mm; similar color, texture, voids, and inclusions as packing plaster
	dirt/soot	
28	ground plaster	sample ends near bottom of layer; similar color, texture, voids, and inclusions as packing plaster
At the rounded end of the sample, most of the layers above the packing plaster are missing, but the first few layers of ground plaster up to a thick paint layer and three subsequent ground plaster layers are still intact.		



Figure 35: Photomicrograph of cross section B1 showing ground plaster and paint layers of a plaster relief. 9.5x magnification under reflected quartz halogen illumination.



Figure 36: Photomicrograph of thin section B2 showing gypsum crystals associated with paint layers. 50x magnification under transmitted cross-polarized light.

CROSS SECTION EXAMINATION		SAMPLE C ₁
Sample Location: Section 6, Çatalhöyük, Turkey		
Substrate: mud brick	Finish: ground and finish plaster	Number of Layers: 160
<p>General Description:</p> <p>The cross section consists of a small bit of mud brick, the preparatory coat, ground plaster, and thinner finish plaster layers. The mud brick is an orange-brown color, with coarse particles of various sizes, shapes, and colors. The subsequent preparatory coat and plaster layers very evenly applied with no accumulation of dirt or soot between layers and nearly parallel boundary surfaces.</p> <p>The preparatory layer is brown with fewer and much smaller coarse fragments than the mud brick. There is still a great variety of colors (black, red, orange, white, clear), and shapes. There are many voids and voids in the preparatory coat, most running parallel to the subsequent plaster layers. Some of the voids contain organic fibers and residues.</p> <p>There are 159 layers of wall plaster. The two types are a ground layer which is often similar in color to the preparatory layer and a white finish plaster. The ground plaster tends to be thicker than the finish plaster and have more voids and inclusions. The finish plaster is very compacted and homogenous in texture with even surfaces. There are no dirt or soot layers between any of the plaster layers. Cracking generally occurs parallel to the plaster layers and near the top of the sample.</p>		

THIN SECTION EXAMINATION		SAMPLE C ₂
Sample Location: Section 6, Çatalhöyük, Turkey		
Substrate: mud brick	Finish: ground and finish plaster	Number of Layers: 160
<p>General Description:</p> <p>The sample consists of a preparatory coat and 159 layers of finish plaster. The preparatory layer is mostly fine particles with 0% to 1% medium and coarse components, mostly quartz and feldspar. The fine particles stain positively for potassium feldspar. The subsequent plaster layers alternate between two types of plaster. The first type, the ground layer, is generally thicker, ranging from 0.100 mm to 0.750 mm. They take up the stain for potassium feldspar very well. The second type of finish plaster, called the finish layer here, is generally from 0.025 mm to 0.100 mm thick. It tends to stain positively for calcite, although in an irregular manner. There are some medium- and coarse-sized constituents, mainly quartz and feldspar, although they are not characteristic of the finish layers and are not above 1% in any layer. Each finish layer is very homogenous in texture and thickness and applied parallel to the flat surface of the preparatory layer. The layers are not as compact as those of sample A, having many voids lined by fine mineral particulates. Thus, the finish layers are very porous. The voids have a channel pattern, disturbing the intergranular continuity. The interfaces between plaster layers are very sharp, indicating a very brief period of exposure before replastering. There is some cracking along the lengths of the plaster layers and a large crack running perpendicular to the stratigraphy which continues from layer 115 to the end of the sample.</p>		

Stratigraphy:		
layer	type of layer	description of layer
1	preparatory layer	loosely compacted light brown plaster; vacuoles and long thin voids, some filled with organic material such as vegetable fibers
2	finish plaster	0.050 mm; deeply stained red, slightly stained yellow; no coarse particles; homogenous texture, very even thickness and regular surfaces; interrupted in some areas by voids and cracks that are larger than the thickness of the layer
3	ground plaster	0.125 mm; slightly stained red, deeply stained yellow; no coarse particles; some voids, including one large one which causes an uneven bottom surface of layer 4, but fairly dense
4	finish plaster	0.050 mm; similar to layer 2 (dense, even texture, no coarses, deeply stained red, slightly stained yellow)
5	ground plaster	0.20 mm; long thin voids; similar to layer 3 (few inclusions, less densely compacted than finish layers, slightly stained red, deeply stained yellow)
6	finish plaster	0.050 mm; dense, even texture, no coarses, deeply stained red, slightly stained yellow; crack along top surface and through the layer about 5 mm long
7	ground plaster	0.075-0.125 mm; less densely compacted than finish layers, slightly stained red, deeply stained yellow; about 15 subround quartz particles of largest diameter 0.060 m distinguish the layer
8	finish plaster	0.075 mm; very even texture and surfaces, undisturbed by cracks and voids; deeply stained red, slightly stained yellow
9	ground plaster	0.575-0.75 mm; many long round voids disturb this layer; large quartz particles of diameter 0.30 mm, which are not a dominant feature
10	finish plaster	0.075-0.25 mm; uneven bottom surface, fairly even top surface; clay bleb across layer and voids which disturb it
11	ground plaster	0.40 mm; long thin voids disturb layer
12	finish plaster	0.060 mm; layer is mostly broken apart by cracking
13	ground plaster	0.40 mm; round vacuoles in layer; 2 or 3 quartz particles with diameter of 0.060 mm
14	finish plaster	0.10 mm; dense, even texture, no coarses, uneven bottom surface, deeply stained red, slightly stained yellow, disturbed in one area by the voids in the previous layer

15	ground plaster	0.325-0.475 mm; fairly compact ground layer
16	finish plaster	0.050 mm; dense, even texture, no coarses, deeply stained red, slightly stained yellow
17	ground plaster	0.50-0.775 mm; fairly compact layer
18	finish plaster	0.075 mm; dense, even texture, no coarse fragments, deeply stained red, slightly stained yellow
19	ground plaster	0.45 mm
20	finish plaster	0.050 mm; dense, even texture, no coarses, deeply stained red, slightly stained yellow
21	ground plaster	0.40 mm; some vacuoles and clay bleb of diameter 0.60 mm
22	finish plaster	0.050 mm; homogenous layer which is disturbed by voids in previous layer
23	ground plaster	0.875 mm; large voids in part of the layer, few coarses, one clay bleb
24	finish plaster	0.050 mm; very even, compact layer with no coarses
25	ground plaster	0.45 mm; some voids, but in general it is a compact layer; small quartz particles of diameter 0.060 mm
26	finish plaster	0.025 mm; very even, compact layer with few coarse fragments
27	ground plaster	0.45 mm; generally compact with round to subround quartz particles of diameter 0.060-0.180 mm which are concentrated in one area which has roughly 20% medium- and coarse-sized particles
28	finish plaster	0.075 mm; compact layer with one round quartz particle of diameter 0.035 mm
29	ground plaster	0.30 mm; many voids throughout layer, some small aggregate particles with diameter less than 0.060 mm
30	finish plaster	0.060 mm; dense, even texture, no coarses, deeply stained red, slightly stained yellow
31	ground plaster	0.325 mm; clay bleb, small quartz particles and other minerals spread out in layer
32	finish plaster	0.050 mm; disturbed by voids and clay bleb of previous layer
33	ground plaster	0.45 mm; voids and coarse particles of diameter less than 0.060 mm
34	finish plaster	0.075 mm; even top and bottom surface, dense, even texture, no coarses
35	ground plaster	0.375 mm; not very compact, coarse particles about 0.1 mm in diameter
36	finish plaster	0.050 mm; uneven bottom surface, even top surface

37	ground plaster	0.25 mm; many voids along the layer; large mineral about 0.5 mm in diameter, possibly quartz
38	finish plaster	0.025-0.075 mm; layer is disturbed by the large mineral fragment in previous layer; fairly even top surface
39	ground plaster	0.100-0.175 mm; voids throughout the layer
40	finish plaster	0.050-0.125 mm; uneven bottom surface, even top surface, compact layer with no coarse particles
41	ground plaster	0.100-0.325 mm, mostly 0.200 mm; coarse particles located throughout the layer, up to 0.1 mm in diameter
42	finish plaster	0.050-0.25 mm; uneven bottom surface, even top surface, no coarse particles
43	ground plaster	0.75-0.10 mm, mostly 0.875 mm; clay blebs and voids throughout layer; large mineral fragment 1.5 mm long
44	finish plaster	0.050 mm; even top and bottom surface, dense, even texture, no coarses
45	ground plaster	0.30 mm; fairly compact layer; some coarse particles which are mostly quartz with diameter up to 0.12 mm
46	finish plaster	0.050 mm; compact layer with even bottom and uneven top surface, no coarse particles
47	ground plaster	0.20 mm; uniform thickness, several coarse-sized particles
48	finish plaster	0.050 mm; very homogenous, compact layer
49	ground plaster	0.050 mm; uniform thickness, several coarse-sized particles
50	finish plaster	0.050 mm; homogenous, compact layer with a subangular quartz particle about .10 mm in diameter
51	ground plaster	0.050 mm; uniform texture, uneven top surface, several coarse-sized particles
52	finish plaster	0.050 mm; uneven bottom surface, even top surface, no coarse particles
both the ground layers and the finish layers from layer 36 to layer 52 are very smooth, even layers; they are compact with no voids		
53	ground plaster	0.175-0.45 mm; uniform thickness, several coarse-sized particles
54	finish plaster	0.075 mm; homogenous, compact layer with uneven bottom surface
55	ground plaster	0.025 mm; similar to previous layer (may be part of it); blue fiber about 0.50 mm long running across layers 54, 55, and 56
56	finish plaster	0.050 mm; many voids, uneven texture, few coarse fragments
57	ground plaster	0.45 mm; fairly compact layer of uneven thickness

58	finish plaster	0.075-0.125 mm; many voids, subround red-orange mineral, probably an iron oxide
59	ground plaster	0.30 mm; even texture and thickness, no coarse particles
60	finish plaster	0.075 mm
61	ground plaster	0.675-0.775 mm; long thin voids, small coarse particles no larger than 0.060 mm in diameter which are mostly quartz, also some yellow particles grouped together in some areas up to 20% coarse ratio; traces of material that look like a finish layer within the layer
62	finish plaster	0.060-0.120 mm; uneven thickness, no coarse fraction
63	ground plaster	0.150-0.725 mm; layer is not very compact, has some coarse particles
64	finish plaster	0.025-0.275 mm; layer is interrupted by coarse particles of the previous layer, uneven texture and thickness; mineralized fiber or shell fragment across layer, voids within the layer
65	ground plaster	0.050-0.0125 mm; even texture, some voids, very little coarse fraction
66	finish plaster	0.125 mm; smooth layer with even texture, thickness, and top and bottom surfaces
67	ground plaster	0.50 mm; many voids, cracking along top of layer, very few coarse particles
68	finish plaster	0.050-0.225 mm; layer broken apart by cracking
69	ground plaster	0.175-0.275 mm; even texture, some cracking between this layer and layer 70, subangular quartz particle about 0.35 mm in diameter
70	finish plaster	0.050-0.100 mm; uneven bottom surface, even top surface, homogenous texture
71	ground plaster	0.575-0.925 mm; many long thin voids, some coarse particles with diameter less than 0.15 mm grouped together (probably quartz and iron oxides)
72	finish plaster	0.025-0.075 mm; uneven thickness and texture; long thin (clay?) bleb about 0.80 mm in length
73	ground plaster	0.225-0.375 mm; even texture and uneven thickness; some coarse particles
74	finish plaster	0.050-0.150 mm; homogenous texture
75	ground plaster	0.0175-0.30 mm; even texture and uneven thickness; some coarse particles
76	finish plaster	0.050-0.1175 mm; uneven bottom surface, fairly even top surface, homogenous texture with no coarse fraction
77	ground plaster	0.475-0.575 mm; small coarse particle with diameter less than 0.060 grouped together in different parts of the layer

78	finish plaster	0.075-0.125 mm; uneven bottom surface, fairly even top surface, no coarse fraction
79	ground plaster	0.200-0.375 mm; fairly compact layer, some sizable voids, a couple of coarse fragments
80	finish plaster	0.050-0.125 mm; uneven thickness and texture
81	ground plaster	0.250-0.325 mm; fairly compact layer, some sizable voids, a couple of coarse fragments
82	finish plaster	0.050-0.100 mm; fairly even thickness and texture; two quartz particles with diameter of about 0.050 mm
83	ground plaster	0.200 mm; even texture and thickness, some small coarse fragments with diameter less than 0.050 mm
84	finish plaster	0.050 mm; even thickness and texture
85	ground plaster	0.150-0.200 mm; even thickness and texture, small coarse fragments of diameter less than 0.050 mm grouped together
86	finish plaster	0.050 mm; even thickness and texture, small coarse fragments of diameter less than 0.050 mm
87	ground plaster	0.250 mm; even thickness and texture, layer has some long voids and cracks, small coarse fragments of diameter less than 0.050 mm
88	finish plaster	0.050 mm; even thickness and texture, small coarse fragments of diameter less than 0.050 mm
both the ground layers and the finish layers from layer 80 to layer 88 are very smooth, even layers; they are compact with very few voids		
89	ground plaster	0.250-0.30 mm; even thickness, sizable voids throughout layer
90	finish plaster	0.075 mm; even thickness and texture, small coarse fragments
91	ground plaster	0.050 mm; even thickness and texture, no coarses or voids
92	finish plaster	0.050 mm; even thickness and texture, a few small coarse
93	ground plaster	0.20-0.35 mm; voids along length of layer, very small aggregate particles
94	finish plaster	0.050-0.225 mm, mostly 0.150 mm; uneven thickness, even texture, very small aggregate particles of diameter of less than 0.025 mm
95	ground plaster	0.20-0.30 mm; even bottom and top surfaces, void from fiber impression, some coarse fraction
96	finish plaster	0.100-0.175 mm; even thickness and texture, no coarse fraction

97	ground plaster	0.150-0.200 mm; some voids but they are not a dominant feature of the layer, coarse particles not larger than 0.10 mm in diameter
98	finish plaster	0.050-0.075 mm; even thickness and texture, no coarse fraction
99	ground plaster	0.375 mm; fairly compact layer, coarse particles up to 0.30 mm in diameter
100	finish plaster	0.050-0.075 mm; even thickness and texture, no coarse fraction
both the ground layers and the finish layers from layer 95 to layer 100 are fairly smooth, even and compact		
101	ground plaster	0.450-0.625 mm; fairly compact layer, coarse particles up to 0.35 mm in diameter
102	finish plaster	0.175-0.50 mm; unusually thick finish layer, uneven bottom and even top surface, quartz particles up to 0.20 mm in diameter
103	ground plaster	0.250 mm; voids along the length of the layer, coarse particles (mostly quartz) up to 0.30 mm in diameter
104	finish plaster	0.100 mm; layer is broken apart and difficult to identify
105	ground plaster	0.250-0.375 mm; fairly compact, even texture, very small aggregate particles
106	finish plaster	0.050-0.075 mm; even thickness and texture, no coarse fraction
107	ground plaster	0.250-0.350 mm; even thickness and texture, small voids throughout layer, small coarse particles
108	finish plaster	0.075-0.150 mm; part of the layer appears to have exfoliated off and is part of layer 109, rough top and bottom surfaces, no coarse fraction
109	ground plaster	0.425-0.550 mm; voids throughout most of the layer, clay blebs and small coarse fragment inclusions
110	finish plaster	0.075 mm; fairly even texture, no coarse particles
111	ground plaster	0.250 mm; even texture, small voids, a few coarse particles
112	finish plaster	0.025-0.050 mm; layer is difficult to identify, homogenous texture
113	ground plaster	0.025-0.050 mm; unusually thin ground layer, even thickness and texture, no coarse fraction
114	finish plaster	0.050-0.125 mm; homogenous texture
115	ground plaster	0.175-0.625 mm, mostly 0.250 mm; uneven thickness, homogenous texture, some voids but not characteristic of the layer, group of aggregate particles with diameters between 0.060 and 0.12 mm

116	finish plaster	0.075-0.375 mm; uneven bottom surface disturbed by layer 115, fairly even top surface
117	ground plaster	0.275-0.400 mm; even thickness and texture, long thin voids and cracks throughout the layer, some grouping of coarse particles of diameter 0.025 to 0.10 mm and larger coarse fragments in layer
118	finish plaster	0.075-0.1 mm; uneven bottom and top surfaces, layer is disturbed by voids in layer 117, crack down part of the layer
119	ground plaster	0.125-0.375 mm, mostly 0.250 mm; homogenous texture, some coarse fraction, but not much
120	finish plaster	0.075-0.175 mm; fairly even top surface, homogenous texture, a couple of coarse particles up to 0.10 mm in diameter
121	ground plaster	0.075-0.325 mm; crack running down the layer nearly its entire length
122	finish plaster	0.175-0.250 mm; homogenous texture, small cracks throughout the layer
123	ground plaster	0.100-0.250 mm; small spread out voids, small coarse fragments
124	finish plaster	0.150-0.250 mm; fairly even texture, even top surface, bottom surface disturbed by voids in layer 123, small cracks
125	ground plaster	0.400 mm; crack down part of the layer, voids in most parts of the layer, a few coarse particles up to 0.150 mm in diameter
126	finish plaster	0.075-0.150 mm; even thickness and texture, no coarse fraction
127	ground plaster	0.075-0.150 mm; some voids and cracking, a few small coarse fragments (mostly quartz)
128	finish plaster	0.125 mm; even thickness and texture, no coarse fraction
129	ground plaster	0.325 mm; voids and cracking down most of the layer, a few coarse particles
130	finish plaster	0.125 mm; homogenous texture, some small cracks, no coarse particles
131	ground plaster	0.025-0.050 mm; unusually thin ground layer, cracks down part of the layer, no coarse fraction
132	finish plaster	0.125 mm; even thickness and texture, no cracking
133	ground plaster	0.100-0.175 mm; even thickness and texture, small amount of cracking, a few voids and a few coarse particles

134	finish plaster	0.125-0.175 mm; even thickness and texture, one coarse particle with diameter of 0.150 mm
layers 117 to 134 are fairly even and compact		
135	ground plaster	0.200-0.275 mm; even thickness and texture, relatively few voids, coarse particles range from subround small quartz and subangular orange particles of diameter 0.060 mm to larger subangular quartz particles with diameter of 0.10 mm
136	finish plaster	0.075 mm; uneven bottom surface, even top surface, small white round and subround coarse particles
137	ground plaster	0.025 mm; homogenous texture
138	finish plaster	0.025 mm; uneven bottom surface, even top surface, some coarse fraction
139	ground plaster	0.150-0.250 mm; uneven thickness, homogenous texture
140	finish plaster	0.025-0.125 mm; uneven bottom surface, even top surface, homogenous texture, no coarse particles
141	ground plaster	0.50 mm; groupings of small subround quartz and red mineral particles, some cracking down the length of the layer
142	finish plaster	0.100-0.250 mm; layer is disturbed by the coarse particles in layer 141, some small coarse fragments, cracking down part of the layer
143	ground plaster	0.125-0.275 mm; many voids, large quartz particle 0.30 mm in diameter
144	finish plaster	0.100 mm; uneven thickness, homogenous texture, layer is disturbed by voids in layer 143
145	ground plaster	0.250 mm; blebs give uneven texture, groupings of subangular and subround particles (mostly quartz) ranging from 0.20 to 0.50 mm in diameter
146	finish plaster	0.050 mm; subangular quartz fraction up to 0.15 mm in diameter
147	ground plaster	0.125-0.250 mm; blebs give uneven texture, groupings of subangular and subround particles (mostly quartz), cracking within the layer
148	finish plaster	0.050 mm; coarse mineral particles of a variety of shapes and types
149	ground plaster	0.050 mm; even thickness and texture
150	finish plaster	0.100 mm; subround green, yellow, and red iron oxide particles
151	ground plaster	0.175-0.225 mm; homogenous texture, small voids, groupings of a few coarse particles of various sizes and shapes

152	finish plaster	0.075-0.125 mm; uneven thickness, a few coarse fragments of various sizes and shapes
153	ground plaster	0.050 mm; many cracks down layer, a few coarse fragments with diameter of 0.060 mm
154	finish plaster	0.050-0.250 mm; uneven thickness, some small quartz inclusions with diameter of 0.35 mm, cracking and voids down length of the layer
155	ground plaster	0.125-0.375 mm; some small coarse particles, cracking down layer
156	finish plaster	0.025-0.125 mm; uneven thickness, some small quartz inclusions with diameter of 0.35 mm, voids in layer
157	ground plaster	0.375-1.00 mm; fairly homogenous texture, coarse (mostly quartz) particles with diameter from 0.060 to 0.150 mm reach 20% of the layer in some areas, cracking down the length of the layer, long thin brown bleb roughly 0.035 by 1.5 mm on top of the layer
158	finish plaster	0.050 mm; even texture and thickness, no coarse fraction, crack down the layer
159	ground plaster	0.375 mm; some groupings of small coarse fragments, some large coarses up to 0.15 mm in diameter, cracking at interface with layer 158
160	finish plaster	goes off of sample so complete thickness cannot be measured, fairly even texture, no coarse fraction
layers 143 to 160 are not very dense and contain many voids		



Figure 37: Photomicrograph of cross section C1 showing the preparatory layer and subsequent plaster layers of a wall plaster. 62.5x magnification under reflected quartz halogen illumination.



Figure 38: Photomicrograph of thin section C2 showing the absence of coarse-size particles in the ground and finish layers. 50x magnification under transmitted cross-polarized light.

CROSS SECTION EXAMINATION		SAMPLE D ₁
Sample Location: unknown location, Çatalhöyük, Turkey		
Substrate: mud brick	Finish: ground and finish plaster	Number of Layers: 10
<p>General Description:</p> <p>There are two zones of mud brick substrate, a preparatory layer, and nine subsequent plaster layers. The first mud brick zone is dark brown and contains many particles of various shapes, sizes, and colors (black, green, red, orange, yellow, white, clear). The next mud brick zone is slightly lighter brown and has fewer and smaller particles with the same degree of color and shape variation. The plaster layers are not as smooth or parallel as those of sample C. There is some dirt accumulation between plaster layers, and finish plasters do not always immediately follow ground layers.</p>		

THIN SECTION EXAMINATION		SAMPLE D ₂
Sample Location: unknown location, Çatalhöyük, Turkey		
Substrate: mud brick	Finish: ground and finish plaster	Number of Layers: 10
<p>General Description:</p> <p>Unlike other thin sections, this sample consists primarily of the mud brick substrate with only a few plaster layers. Within the sample, at least three distinct types of layers exist below the plaster layers. The first layer, presumably the mud brick, is almost entirely medium- and coarse-sized particles which are held together by a matrix of fine particles giving a compact grain structure. They are poorly sorted. Some of the non-fine material stains positively for calcite, but it displays a greater staining for potassium feldspar. The medium and coarse components are over 75% quartz and feldspar, with iron oxides and ebodite present in smaller quantities. There are shell-like fragments in the first mud brick zone. The next layer has less and smaller non-fine material, although it is of the same type. The mineral grains are not as closely packed as those in the first mud brick zone. The binding matrix differs from that of the first layer in color. The third layer, which resembles the preparatory layers of other samples, is mostly fines with only a very small percentage of coarse particles (0-2%). The plaster layers show the same differentiation between layers as other samples. The thinner layers do not stain yellow with sodium cobalt nitrate or red with alizarin red S, and the thicker layers take up each type of stain. Although in cross section more than one layer of ground plaster is visible in between most of the finish layers, distinct ground layers cannot be identified in thin section.</p>		

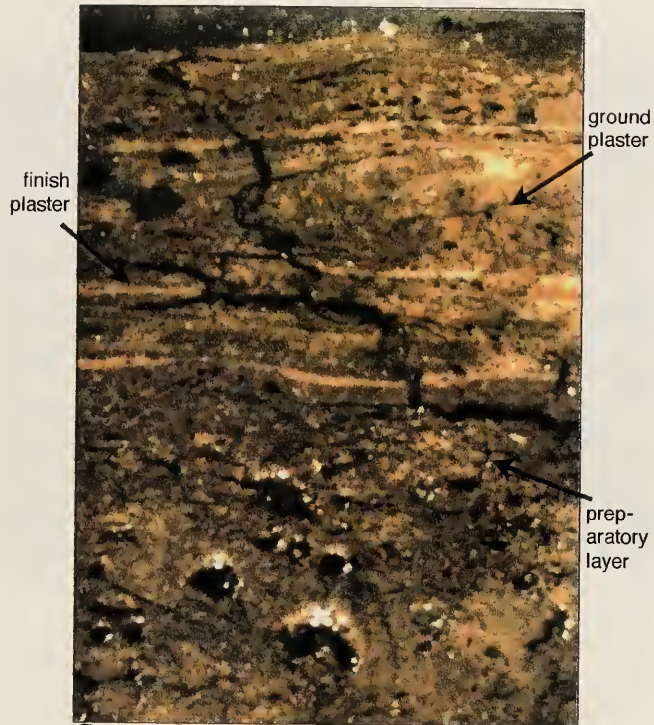


Figure 39: Photomicrograph of cross section D1 showing the preparatory layer and subsequent plaster layers of a wall plaster. 17.5x magnification under reflected quartz halogen illumination.



Figure 40: Photomicrograph of thin section D2 showing an unburned shell in the preparatory coat of the plaster. 50x magnification under transmitted cross-polarized light.

**Appendix D: Scanning Electron Microscopy
Photomicrographs and Energy Dispersive Spectroscopy
Spectra**

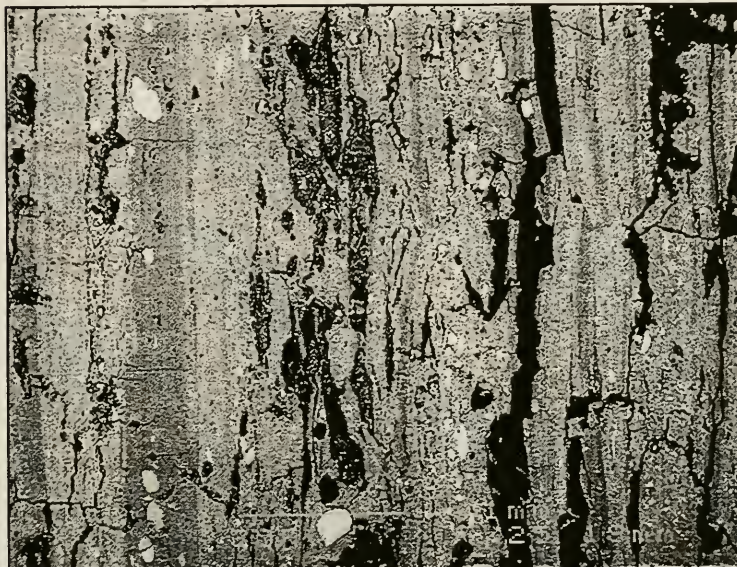


Figure 41: Back-scattered electron image of cross section A1 showing finish plaster (dark vertical areas), ground plaster (light vertical areas) and cracks and voids (black areas). 25x magnification.

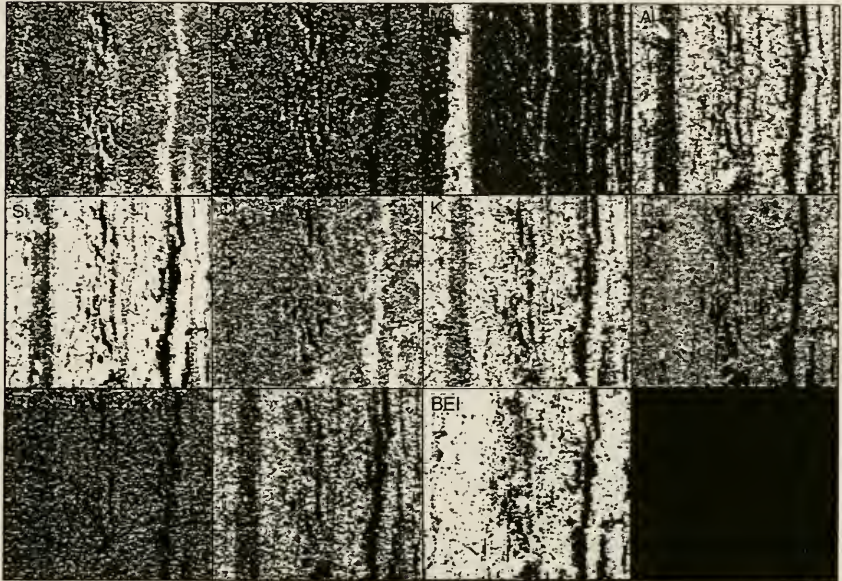


Figure 42: X-ray dot map of figure 40 showing the position of the principle elements in cross section A1. The elements are (upper row, left to right) carbon, oxygen, magnesium, aluminum, (middle row, left to right) silicon, chlorine, potassium, calcium, (bottom row, left to right) titanium, iron, and back-scattered electron image. The finish plaster layers have a relatively high amount of magnesium, whereas the ground plaster has more aluminum and potassium than the finish layers. Calcium is fairly evenly distributed between the two types of plaster and is probably mostly grouped with carbonate to form calcium carbonate.

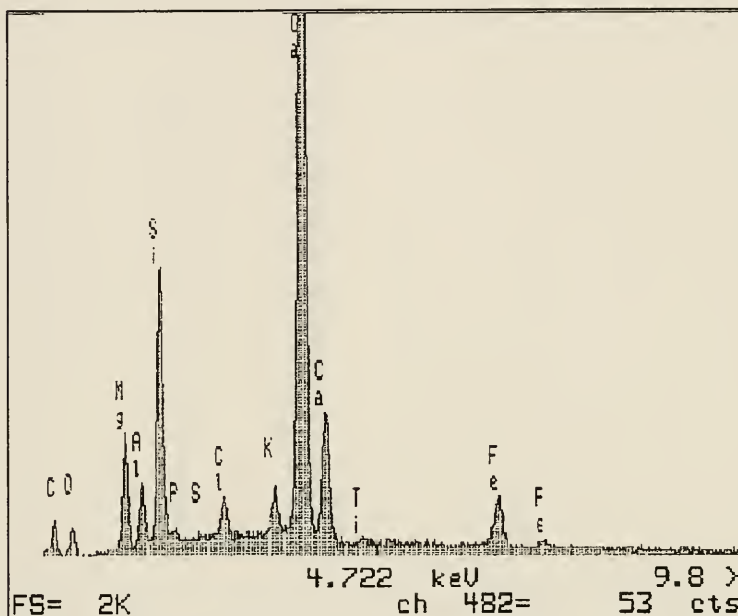


Figure 43: EDS spectrum of a finish plaster layer in cross section A1. The predominant element is calcium, which most likely occurs as calcium carbonate. There is also a relatively large amount of silicon, which may be part of silica quartz or a clay, and magnesium, which may also be attached to a clay.

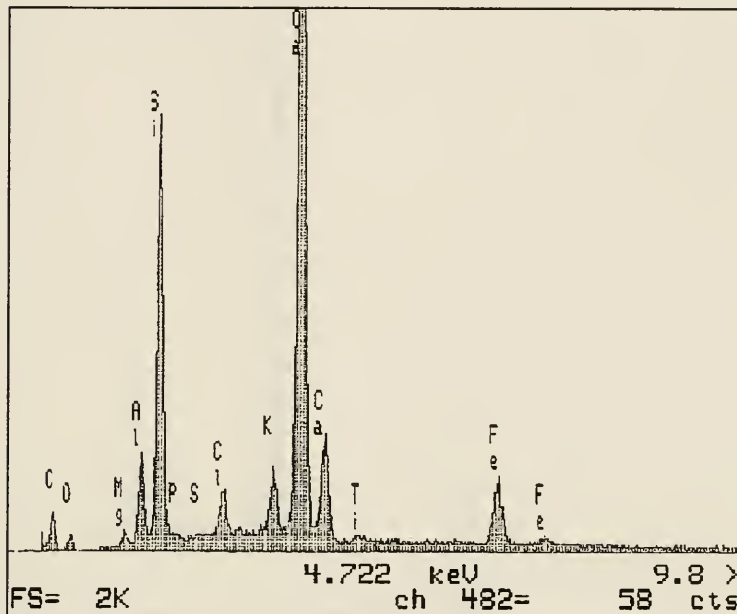


Figure 44: EDS spectrum of a ground plaster layer in cross section A1. Like the finish plaster, the ground plaster has a large amount of calcium and silicon, but it has much less magnesium, relatively.

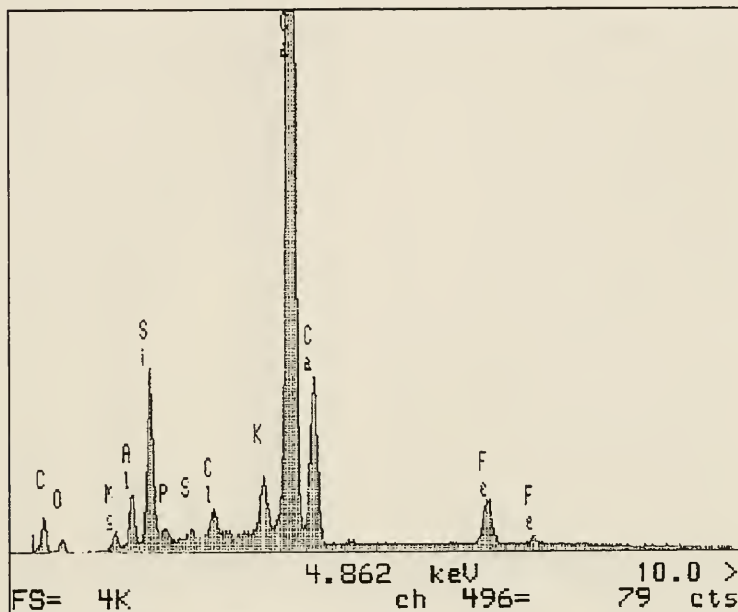


Figure 45: EDS spectrum of the preparatory plaster layer of cross section A1. The preparatory plaster is very similar in relative composition to the ground plaster.

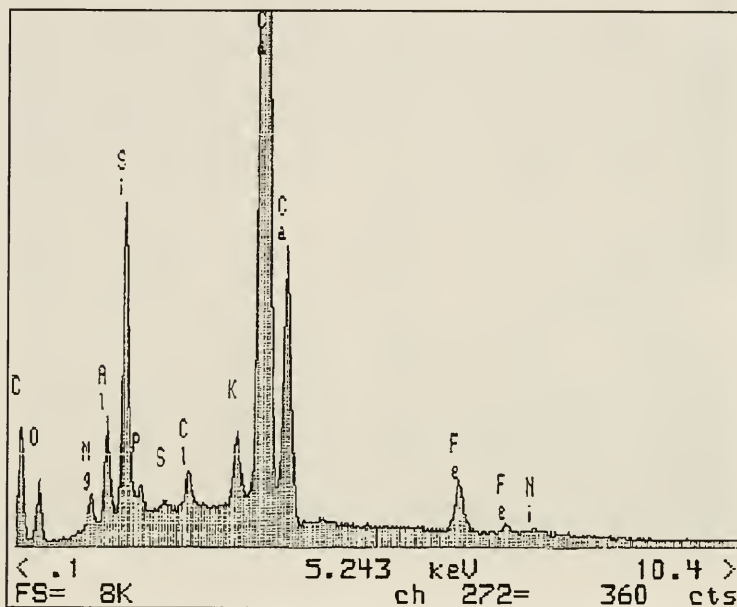


Figure 46: EDS spectrum of a finish plaster layer in cross section C1. Unlike the finish plaster of sample A, the finish plaster of sample C has relatively little magnesium, and is thus more similar to the ground and preparatory plasters based on elemental composition.

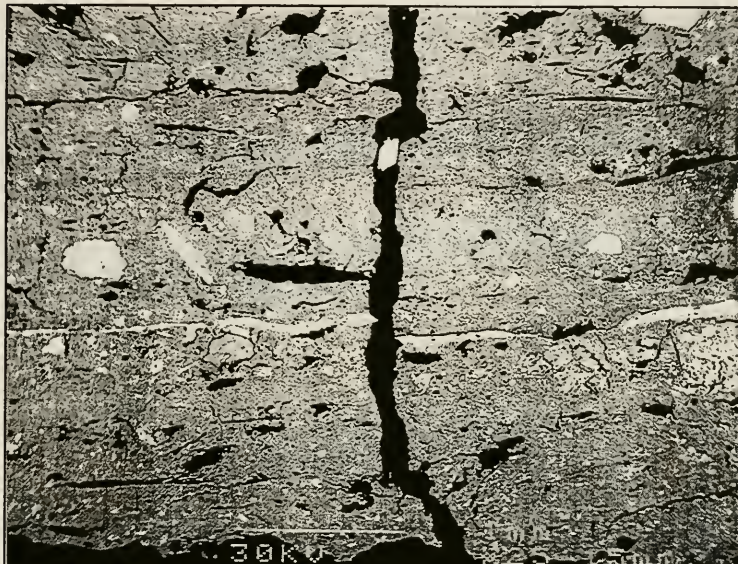


Figure 47: Back-scattered electron image of cross section B1 showing paint layer (light horizontal band) and cracks and voids (black areas). The edge of the relief plaster is at the bottom of the image. 25x magnification.

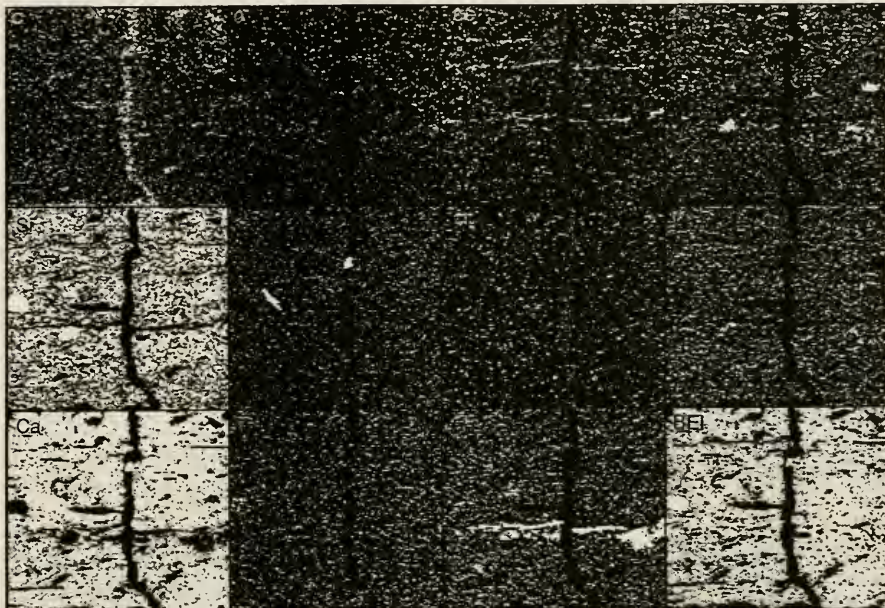


Figure 48: X-ray dot map of figure 47 showing the position of the principle elements in cross section B1. The elements are (upper row, left to right) carbon, oxygen, magnesium, aluminum, (middle row, left to right) silicon, sulfur, chlorine, potassium, (bottom row, left to right) calcium, titanium, iron, and back-scattered electron image. The finish plaster layers have a relatively high amount of magnesium and the paint layer is rich in iron. The round blebs which are bright white in the window for silicon are most likely quartz particles. The white areas in the sulfur window may be gypsum crystals.

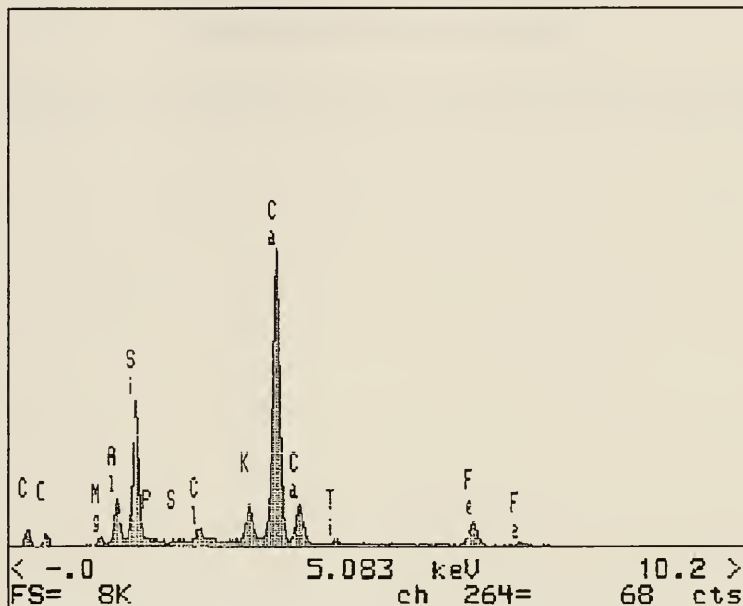


Figure 49: EDS spectrum of a ground plaster layer in cross section B1. The relative intensities of the elemental peaks are nearly identical to the intensities of the peaks for the ground plaster in sample A.

Appendix E: Recent Plaster Consolidation Case Studies

Boulton, Ann. "Some Considerations in the Treatment of Archaeological Plaster Figures from Ain Ghazal, Jordan." In *The American Institute for Conservation of Historic and Artistic Works. Preprints of Papers Presented at the Sixteenth Annual Meeting, New Orleans, Louisiana, June 1-5, 1988*, edited by Sarah Z. Rosenberg, 38-57. Washington, DC: The American Institute for Conservation of Historic and Artistic Works, 1988.

Project Site(s): 'Ain Ghazal, Jordan (ca. 6500-6800 BC)

Nature and Condition of Plaster: sculpted heads of slaked lime and quartz mixture modeled on a reed/rush armature;

reed/rush armature completely deteriorated, lime plaster is severely cracked, in some cases pulverized, and water sensitive

Deterioration Mechanisms: not reported

Consolidant(s) Tested: preconsolidation in the field with Acryloid B-72 (copolymeric acrylic resin);

various consolidants tested: Acryloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), in various concentrations and solvents, three alkoxysilanes (uncatalyzed tetramethoxysilane [MTMOS], uncatalyzed tetramethoxysilane [TMOS], and Conservare OH Stone Strengthener with catalyzed tetraethoxysilane [TEOS]), Acryloid B-72 mixed with the three alkoxysilanes in various concentrations, Dri-Film 104 (silicone resin) mixed with B-72 in various solvents, Raccanello 55050 (acrylic resin) mixed with small amount of silicone resin, and Raccanello 55050 mixed with MTMOS

Tests Performed: qualitative assessment, weight gain, tensile strength, SEM examination

Comments: Acryloid B-72 (5% in acetone, 5% in toluene, and 2%, 5%, and 10% in TMOS) and Conservare OH were found to be the most effective consolidants with Acryloid B-72 (5% in TMOS) giving the most even grain coverage

Bryagin, D. E. "Some Experiments on Strengthening of Ancient Wall Painting Supports with Lime-Casein Solution." In *ICOM Committee for Conservation, 4th Triennial Meeting. Venice, 13-18 October 1975: Preprints*. Paris: ICOM Committee for Conservation, 1975.

Project Site(s): various churches in Russia

Nature and Condition of Plaster: cracking and detaching plaster used as ground for paintings.

Deterioration Mechanisms: not reported

Consolidant(s) Tested: lime-casein solution consisting of mixing one part casein, three parts water and part of this with one part lime

Tests Performed: not reported

Comments: Examination of treated plaster 25 years after original application of lime-casein solution leads author to conclude that there are no deleterious effects and strengthening of plaster is long-lasting.

Cedillo-Alvarez, Luciano. "Stucco: A Report on the Methodology Developed in Mexico." In *In Situ Archeological Conservation: Proceedings of Meetings April 6-13, 1986*, edited by Miguel Angel Corzo, 90-97. Los Angeles: The Getty Conservation Institute, 1987.

Project Site(s): Mexico: Bonampak, Teotihuacán, Palenque, Lambitico, Kohnunlich, Cacaxtla, Comalcalco

Nature and Condition of Plaster: lime plasters with sand and other additives used as smooth surfaces, floor coverings, carved reliefs, and sculpted designs; stucco is crumbling

Deterioration Mechanisms: fluctuations in temperature and humidity; pressure from human action

Consolidant(s) Tested: Mowilith DMIH and DRL (50% solution), DM4 (4% and 10% solutions), lime water; Primal AC-33 (2%, 5%, and 15% solutions), ethyl silicate OH and ethyl silicate H, Endurool, Paraloid B-72 (3%, 4%, and 5% solutions), and Resistol 850 (5%, 10%, and 20% solutions); consolidants were applied using a dropper or brush, injected using venoclysis equipment, syringes, or spray pumps, or absorbed by the fragment by immersion

Tests Performed: not reported

Comments: the use of synthetic resins resulted in detachment of surface layers in which the resin was deposited, especially in areas of high humidity; ethyl silicates have been more successful, but require further evaluation;

the article concludes that there is no proven solution to the problem of consolidating friable stucco work

Chiari, Giacomo. "Treatment of Adobe Friezes in Peru." In *Third International Symposium on Mudbrick (Adobe) Preservation*, edited by Okan Üstünkök and Emre Madran, 39-45. Ankara: ICOM/ICOMOS, 1980.

Project Site(s): Chan Chan, Peru (twelfth to fifteenth centuries AD)

Nature and Condition of Plaster: clay plasters on adobe substrate with carved relief friezes

Deterioration Mechanisms: fluctuations in temperature and humidity, salt efflorescence, wind erosion

Consolidant(s) Tested: ethyl silicate

Tests Performed: not reported

Comments: consolidation with ethyl silicate provides sufficient consolidation of the clay plasters, even after a period of several years, but has the disadvantage of not providing adhesion to the adobe substrate

Cobau, Andreina Costanzi. "In Situ Consolidation of a Roman Fresco Near Ein Yael, Jerusalem." In *ICOM Committee for Conservation, 10th Triennial Meeting. Washington, DC, USA, 22-27 August, 1993: Preprints*. Vol. III, 536-540. Paris: ICOM Committee for Conservation, 1993.

Project Site (s): Ein Yael, Israel (second century AD)

Nature and Condition of Plaster: two part plaster system: scratch coat which is dark with large aggregate and intonaco which is white and pasty with a fine, homogenous texture; faults of cohesion between different layers of the plaster system

Deterioration Mechanisms: soluble salt crystallization, water infiltration, biological growth

Consolidant (s) Tested: Acryloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), 20% in trichloroethane

Comments: The consolidation and other protective measures taken at the site (cleaning, removal of vegetation, metal roof covering) are part of a holistic program of conservation which seeks to preserve the architectural unity of the space. The treatments were surveyed two years after application and determined to still be effective.

Crosby, Anthony. *Tumacacori National Monument, Arizona*. Washington, DC: National Park Service, 1985.

Project Site(s): Tumacacori National Monument, Arizona, United States, seventeenth to nineteenth centuries

Nature and Condition of Plaster: lime plasters on adobe substrate; plasters exfoliating and detaching from substrate

Deterioration Mechanisms: moisture movement through adobe and plaster, differential movement between plaster and adobe

Consolidant(s) Tested: Acryloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), 10% in toluene

Tests Performed: water transmission and absorption, effects of soluble salts, artificial wetting and drying

Comments: consolidant appears to be effective in decreasing moisture transmission and does not promote delamination

Gamarra, Ricardo Morales. "Conservation of Structures and Adobe Decorative Elements in Chan Chan." In *Adobe: International Symposium and Training Workshop on the Conservation of Adobe. Final Report and Major Papers. Lima-Cusco (Peru). 10-22/September 1983*, 83-89. Rome: ICCROM, 1983.

Project Site(s): Chan Chan, Peru (twelfth-fifteenth centuries AD)

Nature and Condition of Plaster: clay plasters on adobe substrate with applied mortar reliefs and decorations which are later shaped by excision and incision

Deterioration Mechanisms: fluctuations in temperature and humidity, salt efflorescence, wind erosion

Consolidant(s) Tested: Primal AC-33 (acrylic emulsion), Mowilith DM-1 H (polyvinyl acetate), Paraloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), Bedacryl 122 X (metracrilate), Calaton CB (soluble nylon), ethyl silicate 40 in 96% ethyl alcohol and hydrochloric solution

Tests Performed: only artificial wetting and drying reported

Comments: ethyl silicate is judged to be the most appropriate consolidant, although it is irreversible and does not provide adhesion to the adobe substrate: provides water resistance and minimal color alteration whereas the other consolidants lead to exfoliation when subjected to humidity and do not allow for future treatment

Gerassimova, N. G. and E. P. Mel'nikova. "The Effect of the Treatment with Polybutyl Methacrylate solutions on Physical and Mechanical Properties of Loess Plaster." In *ICOM Committee for Conservation, 5th Triennial Meeting, Zagreb, 1-8 October 1978: Preprints*. Paris: International Council of Museums, 1978.

Project Site(s): Pendzhikent, Middle Asia (eighth century)

Nature and Condition of Plaster: burnt and unburnt loess plaster with straw added

Deterioration Mechanisms: not reported

Consolidant(s) Tested: polybutyl methacrylate, 10% in xylene and 10% in xylene-ethyl alcohol solution

Tests Performed: exposed porosity, mean pore diameter, water vapor absorption, bending strength

Comments: the consolidants are judged to be equally effective in decreasing hygroscopicity, increasing static bending strength, and altering the pore structure; the main determinant of consolidation ability used is the condition of the plaster

Grissom, Carol A. "Conservation of Neolithic Lime Plaster Statues from 'Ain Ghazal." In *Archaeological Conservation and its Consequences. Preprints of the Contributions to the Copenhagen Congress, 26-30 August 1996*, edited by Ashok Roy and Perry Smith, 70-75. London: International Institute for the Conservation of Historic and Artistic Works, 1996.

Project Site(s): 'Ain Ghazal, Jordan (ca. 6500-6800 BC)

Nature and Condition of Plaster: sculpted heads of slaked lime and quartz mixture modeled on a reed/rush armature;

reed/rush armature completely deteriorated, lime plaster is severely cracked, in some cases pulverized, and water sensitive

Deterioration Mechanisms: compression

Consolidant(s) Tested: preconsolidation with Methocel A15C (1% solution of methyl cellulose;

various consolidants tested: Acryloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), in various concentrations and solvents, Conservare OH and other alkoxysilanes, Acryloid B-72 mixed with alkoxysilanes in various concentrations, mixture of Raccanello E55050 (acrylic silicone oil mixture) with Dow Corning Z6070 (methyltrimethoxysilane)

Tests Performed: tensile strength, depth of penetration, SEM examination

Comments: Conservare OH was the easiest to apply but prevented subsequent cleaning of the statuettes and resulted in slight darkening of the plaster. None of the consolidants used are reversible.

Hanna, S. B. and J. K. Dinsmore. "Conservation of Central Asian Wall Painting Fragments from the Stein Collection in the British Museum." In *The Conservation of Wall Paintings: Proceedings of a Symposium Organized by the Courtauld Institute of Art and the Getty Conservation Institute, London, July 13-16*, edited by Sharon Cather, 77-86. Marina del Rey, CA: Getty Conservation Institute, 1991.

Project Site(s): Stein Collection in British Museum (collected from Dandan-Oilik and Ming-Oi, China

Nature and Condition of Plaster: gypsum surface coat on top of two coats of mud plaster with fibrous additives; extensive cracking and detachment of painted surface coat, friable plaster in danger of collapse

Deterioration Mechanisms: stress due to expansion of wood blocks, cotton wool, tissue paper, and wood shavings in which the plaster fragments were stored.

Consolidant(s) Tested: Paraloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), and Mowital B 30 H (polyvinyl butyral) in a range of solvents, Wacker Stone Strengtheners OH (ethyl silicate), Raccanello E55050 (acrylic silane mixture)

Tests Performed: not reported

Comments: all the consolidants darkened the plaster to a similar degree, which was judged to be within acceptable limits; the Raccanello E55050 was deemed to be the most effective in imparting strength and cohesiveness to the coarse-textured render

Phillips, Morgan. "Alkali-Soluble Acrylic Consolidants for Plaster: A Preliminary Investigation." *Studies in Conservation* 32 (1987): 145-152.

Project Site(s): none

Nature and Condition of Plaster: model plaster: one part plaster of Paris, four parts calcium carbonate (by volume);

c. 1880 ceiling plaster: sanded lime base coat and unsanded skim coat;

1904 wall plaster: lime; crumbling

Deterioration Mechanisms: not reported

Consolidant(s) Tested: alkali-soluble acrylic consolidants: Acrisol WS-24, Emulsion E-2014, Neocryl BT-250, Neocryl BT-175;

Acryloid B-67 used as a standard for comparison

Tests Performed: flexibility of consolidant, hardness, water resistance, rate of penetration, effect of calcium ion, yellowing, loss of solubility

Comments: Neocryl BT-520 and Acrisol WS-24 showed the best performance in a series of laboratory tests for water resistance, rate of penetration, and consolidating effect. Neocryl BT-520 also demonstrates a high degree of resistance to yellowing

Schwartzbaum, Paul M., Constance S. Silver, and Christopher Wheatley. "The Conservation of a Chalcolithic Mural Painting on Mud Brick from the Site of Teleilat Ghassul, Jordan." In *Third International Symposium on Mudbrick (Adobe) Preservation*, edited by Okan Üstüncök and Emre Madran, 177-200. Ankara: ICOM/ICOMOS, 1980.

Project Site(s): Teleilat Ghassul, Jordan (ca. 3000 BC)

Nature and Condition of Plaster: clay plasters applied on mud-brick as the ground for mural paintings; broken into many fragments, mud-brick severely deteriorated and paint friable in some areas

Deterioration Mechanisms: not reported

Consolidant(s) Tested: Wacker Stone Strengthener H (ethyl silicate), 50% in Wacker solvent

Tests Performed: not reported

Comments: the consolidant, applied directly to the mud brick, was absorbed into the plaster support by capillary action and allowed each fragment to be easily handled

Silver, Constance S. "Analyses and Conservation of Pueblo Architectural Finishes in the American Southwest." In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints*, 176-181. Los Angeles: The Getty Conservation Institute, 1990.

Project Site(s): Mesa Verde, Colorado, United States (1100-1300 AD)

Nature and Condition of Plaster: painted earthen plasters on stone support; renderings detached from stone support, delamination between strata, friable rendering and paint, flaking paint

Deterioration Mechanisms: biological growth, burrowing and abrasion by insects and larger animals, and salt efflorescence

Consolidant(s) Tested: Tegavakon T (alkoxysilane) used to treat friable areas of rendering

Tests Performed: not reported

Comments: Conservare H and OH acknowledged to give better results, but not used because of unavailability

Tubb, K. W. "Conservation of the Lime Plaster Statues of 'Ain Ghazal." In *Recent Advances in the Conservation and Analysis of Artifacts*, compiled by James Black, 387-391. London: Summer Schools Press, 1987.

Project Site(s): 'Ain Ghazal, Jordan (ca. 6000 BC)

Nature and Condition of Plaster: sculpted head made from slaked lime and quartz mixture modeled on a reed/rush armature;

reed/rush armature completely deteriorated, lime plaster is severely cracked, in some cases pulverized, and water sensitive

Deterioration Mechanisms: cracking of plaster due to compression during burial

Consolidants Tested: preconsolidation before removal from site with Paraloid B-72 (acrylic resin), 7-10% in toluene;

consolidation with Raccanello E55050 (acrylic silane mixture), 5% in uncatalyzed Dow Corning Z6070 (methyltrimethoxy silane) applied by pipette; excessively dry, friable, and pulverized areas consolidated with Paraloid B-72 (methyl acrylate-ethyl methacrylate copolymeric resin), 10% in acetone

Tests Performed: strengthening, depth of penetration

Comments: Raccanello E55050 consolidant is irreversible, toxic, and causes some cracking and darkening; however, it can be applied repeatedly, has reasonable depth of penetration, allows easy cleaning with acetone, and provides sufficient strengthening of the plaster

Appendix F: Procedures and Data from Laboratory Testing Program

A laboratory testing program, devised in conjunction with Professor Frank Matero, was carried out in order to assess the effectiveness of the chosen consolidating systems. Standard tests, such as those devised and published by the American Society for the Testing of Materials (ASTM), were used. Because these tests are designed primarily for modern materials and construction methods, each test was modified to more accurately determine the effects of consolidation on the earthen plasters of Çatalhöyük. The following standardized tests were selected for use in the laboratory testing program:

Iodine Vapor Test for Determining Depth of Penetration of Consolidants:
Getty Conservation Institute.

Standard Test Method for Abrasion Resistance of Concrete by Sandblasting: ASTM C 418.

Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures: ASTM D 559.

Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens: ASTM D 2726.

Standard Test Method for Specifying Color by the Munsell System: ASTM D 1535

The following system was used to note the test performed and the consolidant used for each test:

Test Performed	Notation	Consolidant Used	Notation
Depth of Penetration	DEP	Untreated	A
Abrasion Resistance	ABR	Epoxy Resin	B
Wet/Dry Cycling	WDC	Acrylic Resin	C
Bulk Specific Gravity	BSG	Ethyl Silicate in methyl ethyl ketone	D
Change in Optical Properties	DEP (same samples as those used for depth of penetration)	Ethyl Silicate in mineral spirits	E
		Ethyl Silicate monomer	F
		Acrylic Resin followed by Ethyl Silicate in mineral spirits	G
		Acrylic Resin followed by Ethyl Silicate monomer	H

Table 10

Thus, sample DEP/C1 is the sample used to determine the depth of penetration achieved when a plaster sample is consolidated with acrylic resin. Sample BSG/G3 is the sample used to determine the bulk specific gravity of the third of three samples treated with ethyl silicate in mineral spirits after preconsolidation with acrylic resin.

Depth of Penetration	
Reference Test	GCI: Iodine Vapor Test for “Determining Depth of Penetration of Consolidants.”
Number of Samples	
per consolidant	1
total	8
Size of Samples	width: 1 inch; length: 2 inches; height: 1.25 inches
Time for Test	
consolidation	28 days
testing	1 day
total	29 days

Purpose: This test is designed to determine the depth of penetration that can be expected of a consolidant which has been applied to a porous material by normal application procedures.

Principles Involved: The amount of consolidant which has been deposited into a treated sample can not always be determined with the unaided eye without the use of dye indicators, elemental analysis, or scanning electron microscopy. Certain reagents can be useful for determining the depth of penetration. Iodine vapor is physically adsorbed onto the surface of organic compounds, but not on inorganic materials such as limestone and calcareous earth plasters. This reaction, which produces a yellow or light brown color, is reversible so that the sample can be used for further testing.

Methodology:

Sampling Method: The samples used were rectangular prisms of plaster cut so that a consolidant could be brushed onto the flat top surface of the plaster, as it might in normal field application. The samples were over one inch high, a representative dimension of the thickness of the wall and relief plasters found *in situ* on the mud brick walls of Çatalhöyük.

Equipment Required: hand saw; glass chamber roughly 12 inches wide, 6 inches thick, and 18 inches high (gas chromatography chamber); glass cover for the chamber; small glass crucibles

Reagents Required: iodine crystals

Preparation of Required Reagents and Samples: The samples were consolidated and allowed to cure for 28 days. The consolidant was applied by brushing on the plaster surface which would be exposed on the wall in order to simulate field application procedures.

Procedure:

The sample to be tested is sawn or broken in half so that a fresh surface of the treated plaster is exposed.

Roughly 20 grams of iodine crystals are placed in each glass crucible. The crucible is placed in the glass chamber. The chamber is covered and the vapor produced by the iodine crystals is allowed to fill the chamber.

The cut sample is placed in the chamber for 15 minutes to one hour.

The change in color due to the reaction of the iodine vapor with the organic material in the consolidant is observed and the depth of color change from the top surface of the sample is noted.

Special Conditions: For best results, the iodine crystals should not be too old, as this will impede reaction the formation of the iodine vapor. Also, the change in color due to the reaction of the iodine vapor with the organic consolidant is difficult to detect on darker colored stone or plaster.

Safety Precautions: Gloves should be worn when handling the iodine crystals and samples to avoid staining human skin.

Data and Observations: The staining due to the reaction of the iodine vapor with the consolidant was observed every 10 minutes for one hour. After about 30 minutes, the staining had reached its maximum intensity. With most samples, color change is uneven in the vertical section of the sample and occurs in horizontally layered zones.

Sample	Depth of Penetration	Comments
DEP/B1	1 centimeter	stain is in uneven zones
DEP/C1	1.5 centimeters	stain is in uneven zones
DEP/D1	2.0 centimeters	stain is in uneven zones
DEP/E1	2.5 centimeters	stain is intense to a depth of 0.75 cm and then weakens
DEP/F1	3 centimeters	stain is intense to a depth of 0.75 cm and then weakens
DEP/G1	3 centimeters	stain is intense to a depth of 1 cm and then weakens
DEP/H1	1.5 centimeters	stain is intense to a depth of 1 cm and then weakens

Table 11

Conclusions: Ethyl silicates achieve the greatest depth of penetration. However, the color change caused by the adsorption of the iodine vapor on the organic material of the ethyl silicate has the lowest intensity. This may be due to the smaller amount of organic material deposited by consolidation with ethyl silicates as compared to the organic epoxy resin and acrylic resin consolidants. Preconsolidation with acrylic resin does not seem to increase the depth of penetration significantly.

Other Tests: The depth of penetration with ethyl silicates and other consolidants can also be determined using reactive dyes, such as fluorochromes. In addition, observation using scanning electron microscopy can be used to determine depth of penetration as well as distribution of the consolidation within the sample on a more microscopic scale.

Abrasion Resistance	
Reference Test	ASTM C 418: "Standard Test Method for Abrasion Resistance of Concrete by Sandblasting."
Number of Samples	
per consolidant	2
total	16
Size of Samples	width: 3 inches; length: 1 inch; height: 0.50 inches
Time for Test	
consolidation	28 days
testing	1 day
total	29 days

Purpose: The resistance of a treated sample to abrasion caused by particulates is an indirect measure of the degree to which intergranular cohesive strength of the sample has been restored. Thus, by comparing the abrasion resistance of an untreated sample and a treated sample, the relative effectiveness of consolidation can be determined.

Principles Involved: Abrasive resistance is a measure of the hardness of a sample, or the aggregation of the component grains. The effectiveness of a consolidant in treating a sample is partly determined by its ability to restore intergranular cohesion. A sample in which the cohesion between grains has been improved will not erode and deteriorate due to the abrading action of liquid water and solid particulates as much as a sample in which the intergranular cohesive strength has not been reestablished.

Methodology:

Sampling Method: The samples required for determining abrasion resistance had to have sufficient surface area to allow for loss of material due to blasting with abrasive powder.

Equipment Required: abrasive powder (50 micron S. S. White Airbrasive Powder No. 3); air compressor (Englo Air Mate air compressor); air abrasive unit (S. S. White Model K Airbrasive Jet Machine Unit); blasting chamber (S. S. White Airbrasive Chamber); metal stand with clamp to hold air abrasive pencil; wooden blocks to support sample; metal plate; watch or clock with second hand; glass microspheres, scale.

Reagents Required: none

Preparation of Required Reagents and Samples: The samples were consolidated by partial immersion to achieve complete consolidation. They should be allowed to stand in normal atmospheric conditions for at least 24 hours and weighed prior to beginning the experiment.

Procedure:

The abrasive material is put into the mixing chamber of the air abrasive unit.

The air compressor is plugged in and turned on. The air pressure in the air compressor is bled out so that the initial air pressure of the air abrasive unit will be less than 20 psi.

The air abrasive unit is plugged in and attached to the air compressor. The air abrasive unit is turned on and the residual abrasive material left in the hoses of the unit is bled out.

The pressure of the air in the air abrasive unit is adjusted to the desired pressure by controlling the pressure in the air compressor.

The air abrasive pencil is attached to a metal stand with a clamp so that it will be held horizontally.

The pre-weighed sample is placed in the blasting chamber and put on wooden blocks so that it will be held in place the desired distance from the nozzle of the air abrasive pencil.

Air without any abrasive material is blasted from the air abrasive pencil for 15 to 30 seconds, holding a metal plate in front of the sample, in order to clear excess powder from the pencil and hoses.

The powder flow is adjusted to the desired setting on the air abrasive unit.

The metal plate is lowered so that abrasive material strikes the surface of the sample.

The sample is abraded for the amount of time judged sufficient to form a depression which can be accurately measured.

The sample is weighed after being abraded and the procedure is repeated two times on each sample.

The relative size of the depression caused by abrasion is determined by measuring the weight of plaster material lost and the weight of the amount of glass microspheres required to fill the hole.

Special Conditions: The abrasive material should be sufficiently dry to avoid clumping together which can clog the hoses of the air abrasive unit.

Safety Precautions: Precautions such as donning a dust mask, safety goggles, and gloves should be taken to avoid bodily harm due to inhalation or abrasion with the abrasive powder. The blasting chamber should be sealed so that the abrasive material stays within the chamber or is sucked into a closed container.

Data and Observations: The parameters used in the test procedure must be determined prior to beginning the test. These are the type of abrasive material, the amount of abrasive relative to the amount of air used to blast the sample (powder flow), the air pressure, the time of blasting, and the distance between the nozzle of the abrasive pencil and the surface of the sample. This was done by testing extra treated and untreated samples until the amount of plaster material lost due to abrasion was judged sufficient for accurate measurement. This was a hole roughly 2 cm in diameter and 2 cm deep at its deepest point. The following parameters were used in the experiment.

abrasive material:	50 micron aluminum oxide
powder flow:	10 (maximum of the air abrasive unit)
air pressure:	60 psi
blasting time:	2 minutes
blasting distance:	3 centimeters

Sample	M_0 (initial mass of sample before abrasion in grams)	M_1 (mass of plaster lost in first abrasion in grams)	M_2 (mass of plaster lost in second abrasion in grams)	M_3 (mass of plaster lost in third abrasion in grams)	Avg.
ABR/A1	41.85 g	0.46 g	0.59	0.62	0.56
ABR/A2	37.44	0.67	0.56	0.53	0.59
ABR/B1	39.27	0.69	0.63	0.66	0.66
ABR/B2	34.63	0.56	0.69	0.73	0.66
ABR/C1	40.34	0.49	0.54	0.49	0.51
ABR/C2	38.17	0.38	0.36	0.37	0.37
ABR/D1	33.81	0.42	0.38	0.34	0.38
ABR/D2	39.26	0.42	0.30	0.32	0.34
ABR/E1	49.11	0.44	0.45	0.55	0.48
ABR/E2	27.89	0.47	0.48	0.38	0.44
ABR/F1	29.29	0.67	0.63	0.57	0.63
ABR/F2	30.65	0.56	0.56	0.68	0.60
ABR/G1	40.51	0.45	0.43	0.37	0.42
ABR/G2	30.02	0.41	0.67	0.51	0.53
ABR/H1	43.36	0.41	0.55	0.57	0.51
ABR/H2	29.90	0.58	0.58	0.58	0.58

Table 12

Sample	Standard deviation	F-value between samples ¹	Treatment	Pooled standard deviation	F-value of treatments compared to untreated (A) ²
ABR/A1	0.098	1.85	A	0.086	—
ABR/A2	0.072				
ABR/B1	0.030	8.80	B	0.067	1.65
ABR/B2	0.089				
ABR/C1	0.021	4.41	C	0.016	28.89
ABR/C2	0.010				
ABR/D1	0.040	2.18	D	0.050	2.96
ABR/D2	0.059				
ABR/E1	0.061	1.23	E	0.058	2.20
ABR/E2	0.055				
ABR/F1	0.060	1.03	F	0.060	2.05
ABR/F2	0.061				
ABR/G1	0.042	9.73	G	0.097	1.27
ABR/G2	0.131				
ABR/H1	0.083	212.03	H	cannot pool data	
ABR/H2	0.0057				

Table 13

¹ The tabulated F-value with 2 degrees of freedom at 95% confidence level is 19.0.

² The tabulated F-value with 5 degrees of freedom at 95% confidence level is 5.05.

Sample	M ₄ (mass of glass beads in first depression in grams)	M ₅ (mass of glass beads in second depression in grams)	M ₆ (mass of glass beads in third depression in grams)	Avg.
ABR/A1	0.34	0.39 g	0.45	0.39
ABR/A2	0.49	0.41	0.41	0.44
ABR/B1	0.54	0.52	0.49	0.52
ABR/B2	0.40	0.49	0.55	0.48
ABR/C1	0.33	0.38	0.35	0.35
ABR/C2	0.27	0.25	0.30	0.27
ABR/D1	0.23	0.20	0.19	0.21
ABR/D2	0.25	0.19	0.21	0.22
ABR/E1	0.33	0.33	0.39	0.35
ABR/E2	0.30	0.33	0.27	0.30
ABR/F1	0.43	0.44	0.44	0.44
ABR/F2	0.43	0.43	0.55	0.47
ABR/G1	0.35	0.28	0.29	0.31
ABR/G2	0.30	0.33	0.38	0.34
ABR/H1	0.41	0.41	0.46	0.43
ABR/H2	0.40	0.40	0.44	0.42

Table 14

Conclusions: The resistance to abrasion inferred to the plaster samples by the epoxy resin is little better than the abrasion resistance of an untreated sample. The samples treated with acrylic resin and ethyl silicate systems in methyl ethyl ketone and in mineral spirits have gained considerable resistance to abrasion, the ethyl silicate-treated samples fairing slightly better. The ethyl silicate monomer consolidant did not increase the resistance to abrasion of the plasters. Preconsolidation with acrylic resin neither increased or decreased the abrasion resistance.

Statistical analysis of the data for abrasion resistance was undertaken to verify the conclusions stated above. The first group of data, the measurement of plaster loss by weight, was used in the statistical analysis because it provides a more accurate measurement of plaster loss. From the F-test at 95% confidence level with two degrees of freedom, there is a significant difference in the precision of the two sets of data for treatment H, indicating that either there is substantial variation between the samples or the treatment creates a significant difference within the sample. Although there may be a significant increase in abrasion resistance, it is impossible to say whether there is or not because of the variation between the two treated samples. Because the calculated F-value is so much greater than the tabulated F-value of 19.0, the data for the two samples cannot be pooled and treatment H is disqualified.

When the data for the two samples within each treatment set are pooled and the F-value computed to compare the precision between treatments, only treatment C, the acrylic resin, has a F-value greater than the tabulated F-value of 5.05 for five degrees of freedom at a 95% confidence level. Because the calculated F-value for treatment D is the next closest to the critical F-value at a 95% confidence level, analysis of variance was used to verify the results of the F-test. First the variance within the treatments, the within-

treatment mean square or s_R^2 , was calculated and determined to be 0.0080. Then the average of all of the measurements was computed and the variance between treatments, between-treatment mean square or s_T^2 , was found to be 0.00112. The ratio of the variances, s_R^2/s_T^2 , is 0.141, well below the critical F-value of 7.71 for one and four degrees of freedom respectively at a 95% confidence level. Thus only the acrylic resin-treated sample appears to have gained a significant increase in abrasion resistance upon consolidation. Using the raw data, it has nearly doubled the resistance to abrasion.

Other Tests: Other tests which can be use to determine abrasion resistance include simple scratch tests using adhesives such as tape or abrasives such as a wire brush. The resistance to abrasion due to water provides a similar measure of the aggregation of a material.

Wet/Dry Cycling	
Reference Test	ASTM D 559: "Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures."
Number of Samples	
per consolidant	3
total	24
Size of Samples	width: 0.50 to 1 inch; length: 0.50 to 1 inch; height: 0.50 to 1 inch
Time for Test	
consolidation	28 days
testing	14 days
total	42 days

Purpose: This test measures the weatherability of untreated and treated material. Because the plaster material of Çatalhöyük will be exposed to periods of rain and other precipitation, followed by dry periods, a qualitative measure of the resistance of treated samples to wet/dry cycles is an important determinant of the effectiveness of consolidation.

Principles Involved: Most consolidants impart at least some degree of hydrophobicity and resistance to moisture to porous materials. The extent to which a consolidated material will resist erosion due to cycles of wetness and dryness can be inferred by comparing the weight loss and deterioration caused by repeated exposure to wet/dry cycling.

Methodology:

Sampling Method: The samples used in the wet/dry cycling testing represent samples that would be exposed to the environment on site. They do not need to be a specific size but should be large enough to observe deterioration such as cracking, delamination, and surface erosion.

Equipment Required: large plastic container; glass rods or glass beads; water; scale

Reagents Required: none

Preparation of Required Reagents and Samples: The samples were consolidated by partial immersion to achieve complete consolidation. They should be allowed to stand in normal atmospheric conditions for at least 24 hours and weighed prior to beginning the experiment.

Procedure:

Glass rods or glass beads are placed on the bottom of the large plastic container and the container is filled with tap water which is allowed to reach room temperature.

The samples are placed in the container and left immersed for five hours.

After a wet cycle the samples are removed from the water and allowed to air dry for 19 hours.

After one wet/dry cycle, the samples are weighed and the cycle is repeated until deterioration and weight loss appear to have ceased.

Special Conditions: In order to insure comparable results, the environmental conditions of the lab such as relative humidity and temperature should be kept as consistent as possible.

Safety Precautions: No special safety precautions are required.

Data and Observations:

Sample	M_0 (initial mass of sample in grams)	M_f (final mass of sample in grams)	Percent of change in mass	Cycles	Comments
WDC/A1	16.19	15.84	- 2.2	10	some intralayer delamination after 8 cycles
WDC/A2	26.82	0	- 100.00	0	complete disintegration after initial immersion
WDC/A3	25.86	0	- 100.00	0	complete disintegration after initial immersion
WDC/B1	18.97	19.34	+ 1.9	6	
WDC/B2	24.89	0	- 100.00	0	complete disintegration after initial immersion

WDC/B3	22.43	0	- 100.00	1	intralayer delamination after initial immersion and complete disintegration after one cycle
WDC/C1	15.18	15.26	+ 0.5	10	
WDC/C2	25.75	23.97	- 6.9	10	intralayer delamination and cracking between layers
WDC/C3	21.21	20.04	- 5.5	10	complete delamination and significant cracking after three cycles
WDC/D1	20.65	20.68	+ 0.1	8	
WDC/D2	26.34	25.25	- 4.1	10	microcracking between layers
WDC/D3	20.79	20.11	- 3.3	10	gross cracking and separation between layers
WDC/E1	7.99	9.10	+ 13.9	4	
WDC/E2	12.52	11.76	- 6.1	4	loss of poorly attached plaster layers
WDC/E3	14.38	13.62	- 5.3	4	
WDC/F1	7.43	7.57	+ 1.8	4	
WDC/F2	9.03	9.76	+8.1	4	
WDC/F3	17.38	17.30	- 0.5	4	
WDC/G1	7.66	7.74	+ 1.0	4	
WDC/G2	8.66	9.52	+9.9	4	
WDC/G3	13.68	13.75	+ 0.5	4	
WDC/H1	6.26	6.38	+ 1.9	4	
WDC/H2	18.18	19.06	+ 4.8	4	
WDC/H3	14.96	15.03	+0.5	4	

Table 15

Samples susceptible to deterioration due to wet/dry cycling tended to disintegrate or delaminate immediately upon exposure to water. The samples which were consolidated using a system with a solvent known to be damaging to the plasters were the most affected by the wet/dry cycling.

Conclusions: Treatment with ethyl silicate in mineral spirits and the ethyl silicate monomer significantly improve the durability of the Çatalhöyük plasters under wet/dry cycling. Epoxy resin as a consolidant has almost no effect on the resistance of the plasters to damage caused by wet/dry cycles, and treatment with acrylic resin and ethyl silicate in methyl ethyl ketone provide some hydrophobicity, but also cause cracking and separation of plaster layers.

Other Tests: Other tests which measure resistance to freeze/thaw cycling, chemical and biological attack, and salt crystallization can also be used to determine the weatherability of a material.

Bulk Specific Gravity	
Reference Test	ASTM D 2726: "Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens."
Number of Samples	
per consolidant	3
total	24
Size of Samples	width: 0.50 to 1 inch; length: 0.50 to 1 inch; height: 0.50 to 1 inch
Time for Test	
consolidation	28 days
testing	1 day
total	29 days

Purpose: The bulk specific gravity of untreated and treated plaster samples are compared in order to determine the change in bulk specific gravity. The change in bulk specific gravity due to consolidation is an important consideration in the comprehensive conservation program for Çatalhöyük, because a significant increase in weight or density of the plasters may affect the procedure required for the detachment and lifting of wall sections.

Principles Involved: The bulk specific gravity of a material will increase upon consolidation because solid material is deposited into the pores or coats the grains of the material. A measure of the change in bulk specific gravity can help to determine how much solid consolidant is deposited into the material.

Methodology:

Sampling Method: The samples used in the test represent the type of plaster that might be lifted as part of the conservation plan for Çatalhöyük. They do not need to be a specific size but should be a shape that can be easily lifted by a string tied around the sample and small enough to fit into a 600 ml beaker.

Equipment Required: water; paraffin wax; tin can; hot plate; large glass dish; graduated cylinder; heavy duty thread; 600 ml glass beaker; thermometer; balance

Reagents Required: none

Preparation of Required Reagents and Samples: The samples were consolidated by partial immersion to achieve complete consolidation. They should be allowed to stand in normal atmospheric conditions for at least 24 hours.

Procedure:

Blocks of paraffin wax are put in the tin can which is placed in a large glass dish filled with water.

The glass dish is put on a hot plate at low temperature to melt the paraffin wax.

The bulk specific gravity of the wax (D_w) is determined by weighing a small amount of the wax, and determining its volume by observing how much water is displaced when the wax is put into a graduated cylinder filled with water. The amount of water displaced is the volume of the wax and the mass of the wax divided by its volume is its bulk specific gravity.

A piece of the heavy duty thread is tied around the sample to be tested so that it can be suspended from a balance. The mass of the sample (m_1) is measured using the balance.

The sample with the string attached is dipped into the melted paraffin wax for 3 to 10 seconds, removed and cooled for 10 to 30 seconds, and the mass of the paraffin wax-coated sample is measured (m_2).

The mass of the wax on the sample (m_w) is m_2 minus m_1 .

The volume of the wax on the sample (V_w) is m_w divided by D_w .

The hydrostatic weight of the coated sample (m_h) is measured by suspending the wax-coated sample from the balance into a 600 ml glass beaker filled with water.

The temperature of the water is measured so that the measured bulk specific gravity can be corrected based on the temperature of the water.

The volume of water displaced by the coated sample (V_1) is m_2 minus m_h .

The volume of the uncoated sample (V_2) is V_1 minus V_w .

The bulk specific gravity of the sample (D) is m_1 divided by V_2 .

Special Conditions: The sample must be completely coated with wax to prevent water from soaking into the sample and altering the hydrostatic weight of the sample. The temperature of the water should be kept constant at 25° C.

Safety Precautions: No special safety precautions are necessary for this test.

Data and Observations:

The density of the paraffin wax was determined to be 0.91 g/ml.

Sample	Bulk Specific Gravity (g/ml)	Sample	Bulk Specific Gravity (g/ml)
BSG/A1	1.59	BSG/E1	1.47
BSG/A2	1.60	BSG/E2	1.48
BSG/A3	1.58	BSG/E3	1.64
BSG/B1	1.27	BSG/F1	1.52
BSG/B2	1.55	BSG/F2	1.65
BSG/B3	1.61	BSG/F3	1.56
BSG/C1	1.56	BSG/G1	1.50
BSG/C2	1.42	BSG/G2	1.60
BSG/C3	1.58	BSG/G3	1.55
BSG/D1	1.60	BSG/H1	1.42
BSG/D2	1.69	BSG/H2	1.44
BSG/D3	1.45	BSG/H3	1.41

Table 16

Conclusions: Consolidation has a negligible effect on the bulk specific gravity of the plaster of Çatalhöyük. In several cases, the bulk specific gravity of consolidated samples

is lower than the average bulk specific gravity of the untreated plaster. This may be due to error during measurement of mass or volume.

Other Tests: The change in weight due to consolidation is also an important factor which will affect the movement of wall sections at Çatalhöyük. This can be determined by simply measuring the weight gain after consolidation.

Change in Optical Properties	
Reference Test	ASTM D 1535: “Standard Test Method for Specifying Color by the Munsell System.”
Number of Samples	
per consolidant	1
total	8 (same samples as those used for depth of penetration)
Size of Samples	width: 1 inch; length: 2 inches; height: 1.25 inches
Time for Test	
consolidation	28 days
testing	1 day
total	29 days

Purpose: The effectiveness of consolidation is diminished if the optical properties are altered so severely that interpretation of an object or feature is compromised. The purpose of determining the change in optical properties is to judge the acceptability of a particular consolidant.

Principles Involved: Change in optical properties such as color can be qualitatively determined by comparing the color of untreated and treated plaster samples to standard color systems such as the Munsell System.

Methodology:

Sampling Method: The samples used to determine the change in optical properties are the same as those used for the measurement of the depth of penetration.

Equipment Required: Munsell System color chips.

Reagents Required: none

Preparation of Required Reagents and Samples: Consolidant was applied to the plaster surface of the sample by brushing in order to simulate field application procedures. Immediately after application, excess consolidant that puddled on the surface of the sample was wiped off with the appropriate solvent.

Procedure:

The color of the sample should be determined prior to consolidation by comparing it to Munsell color chips in direct daylight.

The surface of the sample on which the consolidant has been brushed is then compared to Munsell color chips in direct daylight and the difference in color is determined.

Special Conditions: As much as possible, the lighting conditions under which the sample is compared to the color chips should be kept constant.

Safety Precautions: none

Data and Observations: Color change tends to occur in the ground plaster layers.

Sample	Munsell Value	Comments
untreated	10YR 8/2	sample is light beige with white plaster layers
DEP/B1	10YR 7/2	some slight darkening of the sample
DEP/C1	10YR 7/2	darkening of the light beige plaster areas
DEP/D1	10YR 6/2	darkening of the light beige plaster areas and the white layers
DEP/E1	10YR 7/2	darkening of the light beige plaster areas
DEP/F1	10YR 8/2	almost no change in appearance
DEP/G1	10YR 5/3	extreme darkening to a brown color
DEP/H1	10YR 6/3	some darkening of the plaster surface

Table 17

Conclusions: The ethyl silicate monomer was the most effective consolidant in terms of causing little change to the surface appearance of the plasters from Çatalhöyük. Only the samples treated with acrylic resin followed by ethyl silicate consolidants underwent unacceptable darkening.

Other Tests: More quantitative measurements of change in optical properties can be recorded using a chromometer.

Appendix G: Material Safety Data Sheets of Consolidants Tested

MATERIAL SAFETY DATA SHEET

PRODUCT IDENTIFICATION

ACRYLOID-R B-72 100% Acrylic

Product Code : 05117
 Key : 905250-0
 MSDS Date : 08/27/92
 Supersedes : 04/05/91

Room and Mass Hazard Rating	Scale	
Toxicity	1	4-EXTREME
Fire	1	3-HIGH
Reactivity	0	2-MODERATE
Special		2-SLIGHT
	1	0-INSIGNIFICANT

COMPONENT INFORMATION

No		CAS REG NO.	AMT. (%)
1	Acrylic polymer	Not Registered	10-100
2	Kuivalgel monomer	Not Registered	0.10 MAX
3	Toluene	100 68-3	1.0 MAX

EMERGENCY RESPONSE INFORMATION

FIRST AID PROCEDURES

Inhalation

Move subject to fresh air.

EYE CONTACT

Plush eyes with a large amount of water for at least 15 minutes. Consult a physician if irritation persists.

Skin Contact

Wash affected skin areas thoroughly with soap and water. Consult a physician if irritation persists.

CONTINUED

PRODUCT: ACRYLADIP-R W-78 100% Resin
Rev. 00525W-0
DATE: 08/27/92

CONTINUATION
Ingestion

If swallowed, give 2 glasses of water to drink. Consult a physician.
Never give anything by mouth to an unconscious person.

FIRE FIGHTING INFORMATION

Unusual Hazards

Material as sold is combustible, burns vigorously with intense heat.

Extinguishing Agents

Use the following extinguishing media when fighting fires involving this material:

- carbon dioxide • dry chemical • water spray

Personal Protective Equipment

As in any fire, wear self-contained breathing apparatus (pressure-demand, NIOSH/UL approved or equivalent) and full protective gear.

Special Precautions

Use water spray to control heat.

SPILL OR LEAK HANDLING INFORMATION

Personal Protection

Appropriate protective equipment must be worn when handling a spill of this material. See the PERSONAL PROTECTION MEASURES section for recommendations. If exposed to material during clean-up operations, see the FIRST AID PROCEDURES section for actions to follow.

Procedures

Keep spectators away. Floor may be slippery; use care to avoid falling. Eliminate all ignition sources. Use water spray to keep dusting to a minimum. Transfer spilled material to suitable containers for recovery or disposal.
CAUTION: Keep spills and cleaning runoff out of municipal sewers and open bodies of water.

PROPERTY: ACRYLOID-R R-75 100% Acrylic
 KEY: 905259-6
 DATE: 08/27/92

HAZARD INFORMATION

HEALTH EFFECTS FROM OVEREXPOSURE

Primary Route of Exposure

Inhalation
 Eye Contact
 Skin Contact

Inhalation

Inhalation of monomer vapor from heated product can cause the following:
 - Irritation of nose, throat, and lungs - nausea - headache - dizziness

Eye Contact

Monomer vapors from heated product can cause the following:
 - moderate irritation

Skin Contact

Prolonged or repeated skin contact can cause the following:
 - slight skin irritation

Delayed Effects

Prolonged overexposure to the solvents in this product can cause the following:
 - enlarged liver - kidney effects - cardiac sensitization - irritation of the respiratory tract

FIRE AND EXPLOSIVE PROPERTIES

Flash Point	Not Applicable
Auto-ignition Temperature	234 C/453 F Benimate
Lower Explosive Limit	No Data
Upper Explosive Limit	No Data

REACTIVITY INFORMATION

Instability

This material is considered stable. However, avoid temperatures above 250C/500F, the onset of polymer decomposition. Thermal decomposition is dependent on time and temperature.

CONTINUED

PRODUCT: ACYLOID-8 B-72 100% Resin
 KEY: 905259-A
 DATE: 08/27/92

CONTINUATIONHazardous Decomposition Products

There are no known hazardous decomposition products for this material.

Hazardous Polymerization

Product will not undergo polymerization.

Incompatibility

There are no known materials which are incompatible with this product.

ACCIDENT PREVENTION INFORMATIONENVIRONMENT EXPOSURE INFORMATIONComponent Information

No.		OSHA REG NO.	AMT. (lb)
1	Acrylic polymer	Not Determined	99-999
2	Residual monomers	Not Required	0.1% MAX
3	Solvent	100-00-0	2.0 MAX

Exposure Limit Information

MATERIAL	UNITS	ACRID AND STAS		OSHA		MSDII	
		TWA	STEL	TWA	STEL	GLV	STEL
		None	None	None	None	None	None
		5	5	5	5	5	5
	ppm	50 Skin	70 Skin	100	100	40 Skin	None

5 Not Required

PERSONAL PROTECTION MEASURESRespiratory Protection

A respiratory protection program meeting OSHA 3010-114 and ANSI Z89.2 requirements must be followed whenever multiphase conditions warrant a respirator's use. None required if airborne concentrations are within

PRODUCT: ACRYLOID-R D-71 100% Resin
REV. 905259-8
DATE: 08/27/82

CONTINUATION

ained below the TWA/TLV's listed in the COMPONENT EXPOSURE INFORMATION Section.

Up to 10 times the TWA/TLV: wear a MSHA/NIOSH approved (or equivalent) half-mask, air-purifying respirator.

Up to 1000 ppm organic vapor: wear a MSHA/NIOSH approved (or equivalent) full-facepiece, air-purifying respirator.

Above 1000 ppm organic vapor or Unknown: wear a MSHA/NIOSH approved (or equivalent) self-contained breathing apparatus in the positive pressure mode.

OR,
MSHA/NIOSH approved (or equivalent) full-facepiece airline respirator in the positive pressure mode with emergency escape provisions.

Air-purifying respirators should be equipped with organic vapor cartridges.

Eye Protection

** Use safety glasses (ANSI Z87.1 or approved equivalent).

Hand Protection

Cotton or canvas gloves.

FACILITY CONTROL MEASURES

Ventilation

Use local exhaust ventilation with a minimum capture velocity of 100 ft/min. (0.5 m/sec.) at the point of vapor evolution. Refer to the current edition of Industrial Ventilation: A Manual of Recommended Practice published by the American Conference of Governmental Industrial Hygienists for information on the design, installation, use, and maintenance of exhaust systems.

Other Protective Equipment

Facilities storing or utilizing this material should be equipped with an eyewash facility.

PRODUCT: ACRYLOID-R E-72 100% Resin
KEY: 905250-8
DATE: 08/27/92

STORAGE AND HANDLING INFORMATION

Storage Conditions

Material can burn; limit indoor storage to approved areas equipped with automatic sprinklers. Avoid all ignition sources. The minimum recommended storage temperature for this material is -18C/0F. The maximum recommended storage temperature for this material is 49C/120F.

Handling Procedures

Monomer vapors can be evolved when material is heated during processing operations. See VENTILATION CONTROL MEASURES section for types of ventilation required.

SUPPLEMENTAL INFORMATION

TYPICAL PHYSICAL PROPERTIES

Appearance	Clear
State	Granular solid
Odor Characteristic	Acrylic odor
Viscosity	Not Applicable
Specific Gravity (Water = 1)	1.15
Vapor Density (Air = 1)	Not Applicable
Vapor Pressure	Not Applicable
Melting Point	No Data
Boiling Point	Not Applicable
Solubility in Water	Practically insoluble
Percent Volatility	1.15 Maximum
Evaporation Rate (BAE = 1)	Not Applicable

TOXICITY INFORMATION

Acute Data

Oral LD50 - rat: >5000 mg/kg
Dermal LD50 - rabbit: >3000 mg/kg
Eye Irritation - rabbit: moderate irritation
Skin Irritation - rabbit: slight irritation

Reproductive/Teratology Data

Toluene has been demonstrated to be embryofetotoxic and teratogenic in laboratory animals.

PRODUCT: ACRYLOID-R.D-72 100% Resin

KEY: 905259-8

DATE: 08/27/92

WASTE DISPOSALProcedure

For disposal, incinerate this material at a facility that complies with local, state, and federal regulations.

REGULATORY INFORMATIONWORKPLACE CLASSIFICATIONS

This product is considered hazardous under the OSHA Hazard Communication Standard (29CFR 1910.1200).

This product is a 'controlled product' under the Canadian Workplace Hazardous Materials Information System (WHMIS).

TRANSPORTATION CLASSIFICATIONS

US DOT Hazard Class

NONREGULATED

EMERGENCY PLANNING & COMMUNITY RIGHT-TO-KNOW (EPCRA TITLE 3)Section 311/312 Categorizations (40CFR 370)

This product is a hazardous chemical under 29CFR 1910.1200, and is categorized as an immediate and delayed health hazard.

Section 313 Information (40CFR 372)

This product contains a chemical which is listed in Section 313 above at minimum concentrations. The following listed chemicals are present: (Quantity present is found elsewhere on this MSDS.)

- Toluene (109-86-3)

CERCLA INFORMATION (40CFR 302.6)

This material has a component or components with a reportable quantity under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA) Title III Section 304. The components, CAS numbers, and reportable quantities are listed below. Spills of a component in excess of its reportable quantity must be reported to the National Response Center

CONTINUED

PRODUCT: ACRYLOID-R B-72 100% Resin
KEY: 905259-8
DATE: 06/27/92

CONTINUATION

(1-800-424-2802) and to the appropriate state and local emergency response organizations.
Toluene (100-88-3) 1000lbs.

RCRA INFORMATION

When a decision is made to discard this material as supplied, it does not meet RCRA's characteristic definition of ignitability, corrosivity, or reactivity, and is not listed in 40 CFR 261.33. The toxicity characteristic (TC), however, has not been evaluated by the Toxicity Characteristic Leaching Procedure (TCLP).

CHEMICAL CONTROL LAW STATUS

All components of this product are listed or are excluded from listing on the U.S. Toxic Substances Control Act (TSCA) Chemical Substance Inventory.

STATE RIGHT-TO-KNOW LAWS

Any material listed as "Not Hazardous" in the CAS REG NO column of the COMPONENT INFORMATION Section of this MSDS is trade secret under the provisions of the Pennsylvania Worker and Community Right-to-Know Act.

CALIFORNIA PROPOSITION 65

This product contains a component or components known to the state of California to cause birth defects or other reproductive harm:
- Toluene (100-88-3)
This product contains trace levels of a component or components known to the state of California to cause cancer:
- Benzene (71-43-2)

ACRYLOID-R is a trademark of Rohm and Haas Company or one of its subsidiaries or affiliates.

PRODUCT: ACRYLOID-R B-72 100% Resin
KEY: 905259-8
DATE: 08/27/92

ABBREVIATIONS:

ACGIH - American Conference of Governmental Industrial Hygienists
OSHA - Occupational Safety and Health Administration
TLV - Threshold Limit Value
PEL - Permissible Exposure Limit
TWA - Time Weighted Average
STEL - Short-Term Exposure Limit
BAC - Butyl acetate

* Bar denotes a revision from previous MSDS in this area.

The information contained herein relates only to the specific material identified. Rohm and Haas Company believes that such information is accurate and reliable as of the date of this material safety data sheet, but no representation, guarantee or warranty, express or implied, is made as to the accuracy, reliability, or completeness of the information. Rohm and Haas Company urges persons receiving this information to make their own determination as to the information's suitability and completeness for their particular application.



MATERIAL SAFETY DATA SHEET

97347 (4-85)

MSDS NUMBER

173-11

PAGE. 1

24 HOUR EMERGENCY ASSISTANCE			GENERAL MSDS ASSISTANCE		
SHELL: 713-473-9461 CHEMTREC: 800-424-9300			SHELL: 713-241-4819		
ACUTE HEALTH - + 2	FIRE 1	REACTIVITY 0	HAZARD RATING LEAST - 0 SLIGHT - 1 MODERATE - 2 HIGH - 3 EXTREME - 4		
*For acute and chronic health effects refer to the discussion in Section III					

BE SAFE

 READ OUR PRODUCT
SAFETY INFORMATION
...AND
PASS IT ON
(PRODUCT SAFETY DATA SHEET REQUIRED)

SECTION I		NAME	
PRODUCT	EPONEX(R) RESIN 1510		
CHEMICAL NAME	HYDROGENATED BISPHENOL A-EPICHLOROHYDRIN BASED EPOXY RESIN		
CHEMICAL FAMILY	EPOXY RESIN		
SHELL CODE	43135		

SECTION II-A		PRODUCT/INGREDIENT	
NO.	COMPOSITION	CAS NUMBER	PERCENT
P	EPONEX RESIN 1510	30583-72-3	100
1	TRACE COMPONENTS		
1	EPICHLOROHYDRIN	106-89-8	5-10 PPM
2	DIGLYCIDYL ETHER	2238-07-5	130 PPM

SECTION II-B		ACUTE TOXICITY DATA	
NO.	ACUTE ORAL LD50	ACUTE DERMAL LD50	ACUTE INHALATION LC50
P	5,300 MG/KG (RAT)	>2,000 MG/KG (RABBIT)	NO DATA AVAILABLE

SECTION III HEALTH INFORMATION

THE HEALTH EFFECTS NOTED BELOW ARE CONSISTENT WITH REQUIREMENTS UNDER THE OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200).

EYE CONTACT

BASED ON PRODUCT TESTING, PRODUCT IS IRRITATING TO THE EYES.

SKIN CONTACT

BASED ON PRODUCT TESTING, PRODUCT IS SLIGHTLY IRRITATING TO THE SKIN.

INHALATION

PRODUCT IS NOT EXPECTED TO CAUSE IRRITATION TO THE NOSE, THROAT OR RESPIRATORY TRACT BECAUSE OF ITS LOW VOLATILITY. IF MISTS ARE FORMED PRODUCT MAY PRESENT AN IRRITATION HAZARD VIA INHALATION.

INGESTION

BASED ON PRODUCT TESTING, PRODUCT IS SLIGHTLY TOXIC AND MAY BE HARMFUL IF SWALLOWED.

SIGNS AND SYMPTOMS

IRRITATION AS NOTED ABOVE.

PRODUCT NAME: EPONEX(R) RESIN 1510

MSDS 173-11
PAGE 2**AGGRAVATED MEDICAL CONDITIONS**

PREEXISTING SKIN AND EYE DISORDERS MAY BE AGGRAVATED BY EXPOSURE TO THIS PRODUCT.

OTHER HEALTH EFFECTS

SEE SECTION VI FOR SUPPLEMENTAL HEALTH INFORMATION.

SECTION IV		OCCUPATIONAL EXPOSURE LIMITS			
NO.	OSHA PEL/TWA	OSHA PEL/CEILING	ACGIH TLV/TWA	ACGIH TLV/STEL	OTHER
P	NONE ESTABLISHED				
1	2 PPM (SKIN)		2 PPM (SKIN)		
2	0.1 PPM		0.1 PPM		

SHELL INTERNAL STANDARDS - COMPONENT 1 - (TWA - 1 PPM; 15 MIN. PEAK - 3 PPM).

SECTION V	EMERGENCY AND FIRST AID PROCEDURES
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EYE CONTACT

FLUSH EYES WITH PLENTY OF WATER FOR 15 MINUTES WHILE HOLDING EYELIDS OPEN. GET MEDICAL ATTENTION.

SKIN CONTACT

REMOVE CONTAMINATED CLOTHING/SHOES AND WIPE EXCESS FROM SKIN. FLUSH SKIN WITH WATER. FOLLOW BY WASHING WITH SOAP AND WATER. IF IRRITATION OCCURS, GET MEDICAL ATTENTION. DO NOT REUSE CLOTHING UNTIL CLEANED. *CONTAMINATED LEATHER ARTICLES, INCLUDING SHOES, CANNOT BE DECONTAMINATED AND SHOULD BE DESTROYED TO PREVENT REUSE.

INHALATION

REMOVE VICTIM TO FRESH AIR AND PROVIDE OXYGEN IF BREATHING IS DIFFICULT. GIVE ARTIFICIAL RESPIRATION IF NOT BREATHING. GET MEDICAL ATTENTION.

INGESTION

DO NOT INDUCE VOMITING. IF VOMITING OCCURS SPONTANEOUSLY, KEEP HEAD BELOW HIPS TO PREVENT ASPIRATION OF LIQUID INTO THE LUNGS. GET MEDICAL ATTENTION.*

NOTE TO PHYSICIAN

*IF MORE THAN 2.0 ML PER KG HAS BEEN INGESTED AND VOMITING HAS NOT OCCURRED, EMESIS SHOULD BE INDUCED WITH SUPERVISION. KEEP VICTIM'S HEAD BELOW HIPS TO PREVENT ASPIRATION. IF SYMPTOMS SUCH AS LOSS OF GAG REFLEX, CONVULSIONS OR UNCONSCIOUSNESS OCCUR BEFORE EMESIS, GASTRIC LAVAGE USING A CUFFED ENDOTRACHEAL TUBE SHOULD BE CONSIDERED.

SECTION VI	SUPPLEMENTAL HEALTH INFORMATION
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NOTE: THIS PRODUCT CONTAINS TRACE (5-10 PPM, TYPICAL) RESIDUAL QUANTITIES OF EPICHLORCHYDRIN (ECH), CAS NO. 106-89-8. IT IS VERY UNLIKELY THAT NORMAL WORK PRACTICES WITH THIS PRODUCT COULD RESULT IN MEASURABLE ECH CONCENTRATIONS IN THE WORKPLACE ATMOSPHERE. NEVERTHELESS, YOU SHOULD BE AWARE THAT ECH HAS BEEN REPORTED TO PRODUCE CANCER IN LABORATORY ANIMALS AND TO PRODUCE MUTAGENIC CHANGES IN BACTERIA AND CULTURED HUMAN CELLS. IT HAS BEEN CLASSIFIED BY THE INTERNATIONAL AGENCY FOR RESEARCH ON CANCER (IARC) AS A PROBABLE HUMAN CARCINOGEN (IARC GROUP 2A) BASED ON THE FOLLOWING CONCLUSIONS: HUMAN EVIDENCE - INADEQUATE; ANIMAL EVIDENCE - SUFFICIENT. IT HAS BEEN CLASSIFIED AS AN ANTICIPATED HUMAN CARCINOGEN BY THE NATIONAL TOXICOLOGY PROGRAM (NTP).

PRODUCT NAME: EPONEX(R) RESIN 1510

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SECTION VII

PHYSICAL DATA

BOILING POINT: NOT AVAILABLE
(DEG F)SPECIFIC GRAVITY: 1.09
(H2O=1)VAPOR PRESSURE: NOT AVAILABLE
(MM HG)MELTING POINT: <50
(DEG F)SOLUBILITY: NEGLIGIBLE
(IN WATER)VAPOR DENSITY: >1
(AIR=1)

EVAPORATION RATE (N-BUTYL ACETATE = 1): NOT AVAILABLE

APPEARANCE AND ODOR:
COLORLESS, VISCOUS, COLORLESS LIQUID.

SECTION VIII

FIRE AND EXPLOSION HAZARDS

FLASH POINT AND METHOD:
240 DEG F (PMCC)FLAMMABLE LIMITS % VOLUME IN AIR
LOWER: N/AV UPPER: N/AV

EXTINGUISHING MEDIA

USE WATER FOG, FOAM, DRY CHEMICAL OR CO2.

SPECIAL FIRE FIGHTING PROCEDURES AND PRECAUTIONS

MATERIAL WILL NOT BURN UNLESS PREHEATED. DO NOT ENTER CONFINED FIRE SPACE WITHOUT FULL BUNKER GEAR (HELMET WITH FACE SHIELD, BUNKER COATS, GLOVES AND RUBBER BOOTS), INCLUDING A POSITIVE PRESSURE NIOSH APPROVED SELF-CONTAINED BREATHING APPARATUS. COOL FIRE EXPOSED CONTAINERS WITH WATER.

UNUSUAL FIRE AND EXPLOSION HAZARDS

NO UNUSUAL HAZARDS.

SECTION IX

REACTIVITY

STABILITY: STABLE

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR

CONDITIONS AND MATERIALS TO AVOID:

CAN REACT VIGOROUSLY WITH STRONG OXIDIZING AGENTS, STRONG LEWIS OR MINERAL ACIDS, AND STRONG MINERAL AND ORGANIC BASES/ESPECIALLY PRIMARY AND SECONDARY ALIPHATIC AMINES. REACTION WITH SOME-CURING AGENTS MAY PRODUCE CONSIDERABLE HEAT.

HAZARDOUS DECOMPOSITION PRODUCTS

CARBON MONOXIDE, ALDEHYDES AND ACIDS MAY BE FORMED DURING COMBUSTION.

SECTION X

EMPLOYEE PROTECTION

RESPIRATORY PROTECTION

AVOID BREATHING OF VAPOR OR MIST. IF EXPOSURE MAY OR DOES EXCEED OCCUPATIONAL EXPOSURE LIMITS (SEC. IV) USE A NIOSH-APPROVED RESPIRATOR TO PREVENT OVEREXPOSURE. IN ACCORD WITH 29 CFR 1910.134 USE EITHER AN ATMOSPHERE-SUPPLYING RESPIRATOR OR AN AIR-PURIFYING RESPIRATOR FOR ORGANIC VAPORS.

PROTECTIVE CLOTHING

AVOID CONTACT WITH EYES. WEAR SAFETY GLASSES OR GOGGLES AS APPROPRIATE. AVOID CONTACT WITH SKIN AND CLOTHING. WEAR CHEMICAL-RESISTANT GLOVES AND PROTECTIVE CLOTHING.

ADDITIONAL PROTECTIVE MEASURES

EYE WASH FOUNTAINS AND SAFETY SHOWERS SHOULD BE AVAILABLE FOR EMERGENCY USE.

PRODUCT NAME: EPONEX(R) RESIN 1510

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SECTION XI ENVIRONMENTAL PROTECTION

SPILL OR LEAK PROCEDURES

MAY BURN ALTHOUGH NOT READILY IGNITABLE. USE CAUTIOUS JUDGMENT WHEN CLEANING UP LARGE SPILLS. *** LARGE SPILLS *** WEAR RESPIRATOR AND PROTECTIVE CLOTHING AS APPROPRIATE. SHUT OFF SOURCE OF LEAK IF SAFE TO DO SO. DIKE AND CONTAIN. REMOVE WITH VACUUM TRUCKS OR PUMP TO STORAGE/SALVAGE VESSELS. SOAK UP RESIDUE WITH AN ABSORBENT SUCH AS CLAY, SAND OR OTHER SUITABLE MATERIAL; DISPOSE OF PROPERLY. FLUSH AREA WITH WATER TO REMOVE TRACE RESIDUE. *** SMALL SPILLS *** TAKE UP WITH AN ABSORBENT MATERIAL AND DISPOSE OF PROPERLY.

SECTION XII SPECIAL PRECAUTIONS

STORE IN A COOL, DRY PLACE WITH ADEQUATE VENTILATION. KEEP AWAY FROM OPEN FLAMES AND HIGH TEMPERATURES.

CONTAINERS, EVEN THOSE THAT HAVE BEEN EMPTIED, CAN CONTAIN HAZARDOUS PRODUCT RESIDUES. WASH WITH SOAP AND WATER BEFORE EATING, DRINKING, SMOKING, APPLYING COSMETICS, OR USING TOILET FACILITIES. LAUNDRY CONTAMINATED CLOTHING BEFORE REUSE. CONTAMINATED LEATHER ARTICLES INCLUDING SHOES CANNOT BE DECONTAMINATED AND SHOULD BE DESTROYED TO PREVENT REUSE.

SECTION XIII TRANSPORTATION REQUIREMENTS

DEPARTMENT OF TRANSPORTATION CLASSIFICATION:
NOT HAZARDOUS BY D.O.T. REGULATIONS

D.O.T. PROPER SHIPPING NAME:
NONE

OTHER REQUIREMENTS:
NOT REGULATED

SECTION XIV OTHER REGULATORY CONTROLS

THIS PRODUCT IS LISTED ON THE EPA/TSCA INVENTORY OF CHEMICAL SUBSTANCES.

PROTECTION OF STRATOSPHERIC OZONE (PURSUANT TO SECTION 611 OF THE CLEAN AIR ACT AMENDMENTS OF 1990): PER 40 CFR PART 82, THIS PRODUCT DOES NOT CONTAIN NOR WAS IT DIRECTLY MANUFACTURED WITH ANY CLASS I OR CLASS II OZONE DEPLETING SUBSTANCES.

IN ACCORDANCE WITH SARA TITLE III, SECTION 313, THE ENVIRONMENTAL DATA SHEET (EDS) SHOULD ALWAYS BE COPIED AND SENT WITH THE MSDS.

SECTION XV STATE REGULATORY INFORMATION

THE FOLLOWING CHEMICALS ARE SPECIFICALLY LISTED BY INDIVIDUAL STATES; OTHER PRODUCT SPECIFIC HEALTH AND SAFETY DATA IN OTHER SECTIONS OF THE MSDS MAY ALSO BE APPLICABLE FOR STATE REQUIREMENTS. FOR DETAILS ON YOUR REGULATORY REQUIREMENTS YOU SHOULD CONTACT THE APPROPRIATE AGENCY IN YOUR STATE.

STATE LISTED COMPONENT	PERCENT	STATE CODE
EPICHLOROHYDRIN (CAS NO: 106-89-8)	5-10 PPM	MA, CA65

PRODUCT NAME: EPONEX(R) RESIN 1510

MSDS 173-11
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DIGLYCIDYL ETHER

(CAS NO: 2238-07-5)

130 PPM

MA

CA = CALIFORNIA HAZ. SUBST. LIST; CA65 = CALIFORNIA SAFE DRINKING WATER AND TOXICS ENFORCEMENT ACT LIST; FL = FLORIDA SUBST. LIST; IL = ILLINOIS TOX. SUBST. LIST; MA = MASSACHUSETTS SUBST. LIST; ME = MAINE HAZ SUBST. LIST; MN = MINNESOTA HAZ. SUBST. LIST; NJ = NEW JERSEY HAZ. SUBST. LIST; PA = PENNSYLVANIA HAZ. SUBST. LIST; RI = RHODE ISLAND HAZ. SUBST. LIST.

THIS PRODUCT CONTAINS A CHEMICAL OR CHEMICALS KNOWN TO THE STATE OF CALIFORNIA TO CAUSE CANCER AND/OR REPRODUCTIVE TOXICITY.

SECTION XVISPECIAL NOTES

SEE ENVIRONMENTAL DATA SHEET FOR WASTE DISPOSAL AND OTHER ENVIRONMENTAL INFORMATION. THIS MSDS REVISION HAS CHANGES IN SECTION(S) VI AND XV AND EDS.

THE INFORMATION CONTAINED HEREIN IS BASED ON THE DATA AVAILABLE TO US AND IS BELIEVED TO BE CORRECT. HOWEVER, SHELL MAKES NO WARRANTY, EXPRESSED OR IMPLIED REGARDING THE ACCURACY OF THESE DATA OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF. SHELL ASSUMES NO RESPONSIBILITY FOR INJURY FROM THE USE OF THE PRODUCT DESCRIBED HEREIN.

DATE PREPARED: SEPTEMBER 01, 1992
-----J. C. WILLETT

BE SAFE

READ OUR PRODUCT
SAFETY INFORMATION ...AND PASS IT ON
(PRODUCT LIABILITY LAW
REQUIRES IT)

SHELL OIL COMPANY
PRODUCT SAFETY AND COMPLIANCE
P. O. BOX 4320
HOUSTON, TX 77210

MATS-175-002

MATERIAL SAFETY DATA SHEET

ProSoCo, Inc.

I PRODUCT IDENTIFICATION

MANUFACTURER'S NAME ProSoCo, Inc. EMERGENCY TELEPHONE NUMBER: 913/281-2700
 AND ADDRESS: P.O. Box 171677
 Kansas City, Kansas 66117

PRODUCT TRADE NAME: Conservac® OH Stone Strengthener

II HAZARDOUS INGREDIENTS

CHEMICAL NAME	(COMMON NAME)	CAS NO.	NFPA CODE	ACGIH TLV/TWA	OSHA PEL/TWA
2-Propanone	(Acetone)	67-64-1	1,3,0,-	750 ppm	750 ppm
Ethyl Alcohol	(Ethanol)	64-17-5	3,3,0,-	1000 ppm	1000 ppm
2-Butanone	(Methyl Ethyl Ketone)	78-93-3	1,3,0,-	200 ppm	200 ppm
Tetraethylorthosilicate	(Ethyl Silicate)	78-10-4	2,2,0,-	10 ppm	10 ppm
Organic Tin Compound	(-)		Unknown	0.1 mg/m ³ (s.c.-skin)	Unknown

Percent content of hazardous ingredients withheld as trade secret pursuant to Massachusetts regulations.

* CONTAINS SOME OR ALL OF THE LISTED INGREDIENTS.

III PHYSICAL DATA

	BOILING POINT (°F)	VAPOR PRESSURE (mm Hg)	VAPOR DENSITY (Air=1)	EVAPORATION RATE (1=Butyl Acetate)
2-Propanone	133	182 (68°F)	2.0	7.7
Ethyl Alcohol	180	33 (68°F)	3.0	1.9
2-Butanone	175	75 (68°F)	2.5	3.8
Tetraethylorthosilicate	302.6	1.0 (68°F)	Unknown	Unknown
Organic Tin Compound	> 401	0.2 (320°F)	N/A	Very slow

	SPECIFIC GRAVITY	SOLUBILITY IN WATER	APPEARANCE AND ODOR
Conservac® OH Stone Strengthener	0.921	Negligible	Clear liquid, sweet ketone odor

IV. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (METHOD): 36°F (T.O.C.)

FLAMMABLE LIMITS: Not determined.

EXTINGUISHING MEDIA: Carbon dioxide, dry chemical, alcohol-resistant foam, or water fog. Do not use direct water stream. Do not use direct water stream. Avoid accumulation of water as product will float.

SPECIAL FIRE FIGHTING PROCEDURES: Do not enter confined fire space without proper protective equipment including a NIOSH/MSHA approved self-contained breathing apparatus. Cool fire exposed containers, surrounding equipment and structures with water.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Vapors are heavier than air and may accumulate in low areas or areas inadequately ventilated. Vapors may also travel along the ground to be ignited at location distant from handling site; flashback of flame to handling site may occur. Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively.

FLAMMABLE!!! Keep container tightly closed. Isolate from oxidizers, heat, and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions.

V. HEALTH HAZARD DATA

PRIMARY ROUTES OF EXPOSURE: Inhalation, skin, eyes.

CARCINOGEN INFORMATION: Not listed (OSHA, IARC, NTP).

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: No applicable information found.

EFFECTS OF OVEREXPOSURE: Highly irritating to eyes. Moderately irritating to skin. High concentrations may produce anesthetic or narcotic effect. May cause kidney and liver damage and temporary disorder of sight.

EYE CONTACT: Liquid is highly irritating to the eyes. Vapors are also irritating. Possible moderate corneal injury and temporary disorder of sight.

SKIN CONTACT: Liquid is moderately irritating to the skin. Repeated, prolonged contact can result in defatting to the skin which may lead to dermatitis.

INHALATION: Breathing high vapor concentrations or prolonged breathing of lower concentrations can cause nose and throat irritation and may cause headache, dizziness and loss of consciousness.

NOTE: Minor embryotoxic/fetotoxic effects have been observed in laboratory rats exposed to over 1,000 ppm of MEK for most of the gestation period by the inhalation route (5X the OSHA-PEL/TWA).

INGESTION: Liquid ingestion may result in vomiting; aspiration of liquid into the lungs must be avoided as liquid contact with the lungs can result in chemical pneumonitis and pulmonary edema/hemorrhage.

EMERGENCY AND FIRST AID PROCEDURES:

- EYE CONTACT:** If in eyes, flush with large amounts of water for 15 minutes, holding eyelids apart to ensure flushing of the entire eye surface. Get medical attention. If persistent irritation occurs, get medical attention.
- SKIN CONTACT:** Wash with soap and water. Remove contaminated clothing and do not reuse until laundered. If persistent irritation occurs, get medical attention.
- INHALATION:** Remove victim to fresh air and provide oxygen if breathing is difficult. Give artificial respiration if not breathing. Get immediate medical attention.
- INGESTION:** **DO NOT INDUCE VOMITING!** Get immediate medical attention. If vomiting occurs spontaneously, keep victim's head below hips to prevent breathing vomitus into lungs.

VI REACTIVITY DATA

STABILITY: Stable.

CONDITIONS TO AVOID: Oxidizing materials, nitric plus acetic acid, and nitric plus sulfuric acid.

INCOMPATIBILITY (MATERIALS TO AVOID): Oxidizing materials, acids, and alkalis.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS: Carbon monoxide, carbon dioxide, silicon dioxide and traces of incompletely burned hydrocarbons. Ethyl alcohol from hydrolysis.

VII SPILL OR LEAK PROCEDURES

SPILL, LEAK AND WASTE DISPOSAL PROCEDURES: STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Large Spills: Eliminate potential sources of ignition. Wear appropriate respirator and other protective clothing. Shut off source of leak only if safe to do so. Dike and contain. Remove with explosion-proof equipment. Soak up residue with a noncombustible absorbent such as clay or vermiculite; place in drums for proper disposal. Flush area with water to remove trace residue; dispose of flush solutions in drums.

Small Spills: Soak up with a noncombustible absorbent and place in drums for disposal. Flush area with water to remove trace residue; collect flush solutions for disposal.

Handling equipment must be grounded to prevent sparking.

WASTE DISPOSAL METHODS: Dispose of in a facility approved under RCRA regulations for hazardous waste. Containers must be leak-proof and properly labeled.

VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION: If Threshold Limit Value (TLV) of the product or any component is exceeded, a NIOSH/MSHA jointly approved air-supplied respirator is advised in absence of proper environmental control. OSHA regulations also permit other NIOSH/MSHA respirators under specified conditions. (See your safety equipment supplier.) Engineering or administrative controls should be implemented to reduce exposure.

VENTILATION: Provide sufficient general and/or local exhaust ventilation to maintain exposure below TLV(s). Use explosion-proof ventilation as required to control vapor concentrations below the TLV(s).

PROTECTIVE CLOTHING: Wear protective clothing as required to prevent skin contact.

PROTECTIVE GLOVES: Wear solvent-resistant gloves, such as butyl rubber.

EYE PROTECTION: Chemical splash goggles in compliance with OSHA regulations are advised; however, OSHA regulations also permit other type safety glasses. Do not wear contact lenses because they may contribute to the severity of an eye injury. (Consult your safety equipment supplier.)

OTHER PROTECTIVE EQUIPMENT: Solvent-resistant boots and headgear. Safety shower and eyewash.

IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Store away from oxidizing materials, in a cool, dry place with adequate ventilation. Keep away from heat and open flames. Keep container tightly closed when not dispensing product.

Wash up with soap and water before eating, drinking, smoking or using toilet facilities. Launder contaminated clothing before reuse.

Containers of this material may be hazardous when emptied, since emptied containers retain product residues (vapor, liquid, and/or solid). All hazard precautions given in the Data sheet must be observed.


Ground equipment to prevent accumulation of static charge. Containers must be bonded and grounded when pouring or transferring materials.

OTHER PRECAUTIONS: Environmental Hazards - Keep out of surface water and watercourses or sewers entering or leading to surface waters.

DISCLAIMER:

The information contained on the Material Safety Data Sheet has been compiled from data considered accurate. This data is believed to be reliable, but it must be pointed out that values for certain properties are known to vary from source to source. ProSoCo, Inc. expressly disclaims any warranty express or implied as well as any liability for any injury or loss arising from the use of this information or the materials described. This data is not to be construed as absolutely complete since additional data may be desirable when particular conditions or circumstances exist. It is the responsibility of the user to determine the best precautions necessary for the safe handling and use of this product for his unique application. This data relates only to the specific material designated and is not to be used in combination with any other material. Many federal and state regulations pertain directly or indirectly to the product's end use and disposal of containers and unused material. It is the purchaser's responsibility to familiarize himself with all applicable regulations.

DATE OF PREPARATION: January 28, 1993

MATERIAL SAFETY DATA SHEET **ProSoCo, Inc.****I PRODUCT IDENTIFICATION**

MANUFACTURER'S NAME AND ADDRESS: ProSoCo, Inc.
P.O. Box 171677
Kansas City, Kansas 66117

EMERGENCY TELEPHONE NUMBER: 913/281-2700

PRODUCT TRADE NAME: Conservare® OH40 Stone Strengtheners

II HAZARDOUS INGREDIENTS

CHEMICAL NAME	(COMMON NAME)	CAS NO.	NFPA CODE	ACGIH TLV/TWA	OSHA PEL/TWA
Ethyl Alcohol	(Ethanol)	64-17-5	3,3,0,-	1000 ppm	1000 ppm
Tetraethylorthosilicate	(Ethyl Silicate)	78-10-4	2,2,0,-	10 ppm	10 ppm
Organic Tin Compound	(-)	-	Unknown	0.1 mg/m ³ (s _c -skin)	Unknown

Percent content of hazardous ingredients withheld as trade secret pursuant to Massachusetts regulations.

* CONTAINS SOME OR ALL OF THE LISTED INGREDIENTS.

III PHYSICAL DATA

	BOILING POINT (°F)	VAPOR PRESSURE (mm Hg)	VAPOR DENSITY (Air=1)	EVAPORATION RATE (1=Butyl Acetate)
Ethyl Alcohol	180	33 (68°F)	3.0	1.9
Tetraethylorthosilicate	302.6	1.0 (68°F)	Unknown	Unknown
Organic Tin Compound	> 401	0.2 (320°F)	N/A	Very slow

	SPECIFIC GRAVITY	SOLUBILITY IN WATER	APPEARANCE AND ODOR
Conservare® OH40 Stone Strengtheners	0.871	Negligible	Clear liquid, sweet ketone odor

IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (METHOD): 55°F [12°C] (T.O.C.)

FLAMMABLE LIMITS: Not determined.

EXTINGUISHING MEDIA: Carbon dioxide, dry chemical, alcohol-resistant foam, or water fog. Do not use direct water stream. Do not use direct water stream. Avoid accumulation of water as product will float.

SPECIAL FIRE FIGHTING PROCEDURES: Do not enter confined fire space without proper protective equipment including a NIOSH/MSHA approved self-contained breathing apparatus. Cool fire exposed containers, surrounding equipment and structures with water.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Vapors are heavier than air and may accumulate in low areas or areas inadequately ventilated. Vapors may also travel along the ground to be ignited at location distant from handling site; flashback of flame to handling site may occur. Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively.

FLAMMABLE!!! Keep container tightly closed. Isolate from oxidizers, heat, and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions.

V HEALTH HAZARD DATA

PRIMARY ROUTES OF EXPOSURE: Inhalation, skin, eyes.

CARCINOGEN INFORMATION: Not listed (OSHA, IARC, NTP).

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: No applicable information found.

EFFECTS OF OVEREXPOSURE: Highly irritating to eyes. Moderately irritating to skin. High concentrations may produce anesthetic or narcotic effect. May cause kidney and liver damage and temporary disorder of sight.

EYE CONTACT: Liquid is highly irritating to the eyes. Vapors are also irritating. Possible moderate corneal injury and temporary disorder of sight.

SKIN CONTACT: Liquid is moderately irritating to the skin. Repeated, prolonged contact can result in defatting to the skin which may lead to dermatitis.

INHALATION: Breathing high vapor concentrations or prolonged breathing of lower concentrations can cause nose and throat irritation and may cause headache, dizziness and loss of consciousness.

NOTE: Minor embryotoxic/fetotoxic effects have been observed in laboratory rats exposed to over 1,000 ppm of MEK for most of the gestation period by the inhalation route (5X the OSHA-PEL/TWA).

INGESTION: Liquid ingestion may result in vomiting; aspiration of liquid into the lungs must be avoided as liquid contact with the lungs can result in chemical pneumonitis and pulmonary edema/hemorrhage.

EMERGENCY AND FIRST AID PROCEDURES:

- EYE CONTACT:** If in eyes, flush with large amounts of water for 15 minutes, holding eyelids apart to ensure flushing of the entire eye surface. Get medical attention. If persistent irritation occurs, get medical attention.
- SKIN CONTACT:** Wash with soap and water. Remove contaminated clothing and do not reuse until laundered. If persistent irritation occurs, get medical attention.
- INHALATION:** Remove victim to fresh air and provide oxygen if breathing is difficult. Give artificial respiration if not breathing. Get immediate medical attention.
- INGESTION:** **DO NOT INDUCE VOMITING!** Get immediate medical attention. If vomiting occurs spontaneously, keep victim's head below hips to prevent breathing vomitus into lungs.

VI REACTIVITY DATA

- STABILITY:** Stable.
- CONDITIONS TO AVOID:** Oxidizing materials, nitric plus acetic acid, and nitric plus sulfuric acid.
- INCOMPATIBILITY (MATERIALS TO AVOID):** Oxidizing materials, acids, and alkalis.
- HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS:** Carbon monoxide, carbon dioxide, silicon dioxide and traces of incompletely burned hydrocarbons. Ethyl alcohol from hydrolysis.

VII SPILL OR LEAK PROCEDURES

- SPILL, LEAK AND WASTE DISPOSAL PROCEDURES:** STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Large Spills: Eliminate potential sources of ignition. Wear appropriate respirator and other protective clothing. Shut off source of leak only if safe to do so. Dike and contain. Remove with explosion-proof equipment. Soak up residue with a noncombustible absorbent such as clay or vermiculite; place in drums for proper disposal. Flush area with water to remove trace residue; dispose of flush solutions in drums.
- Small Spills: Soak up with a noncombustible absorbent and place in drums for disposal. Flush area with water to remove trace residue; collect flush solutions for disposal.

Handling equipment must be grounded to prevent sparking.

- WASTE DISPOSAL METHODS:** Dispose of in a facility approved under RCRA regulations for hazardous waste. Containers must be leak-proof and properly labeled.

VIII SPECIAL PROTECTION INFORMATION

- RESPIRATORY PROTECTION:** If Threshold Limit Value (TLV) of the product or any component is exceeded, a NIOSH/MSHA jointly approved air-supplied respirator is advised in absence of proper environmental control. OSHA regulations also permit other NIOSH/MSHA respirators under specified conditions. (See your safety equipment supplier.) Engineering or administrative controls should be implemented to reduce exposure.

VENTILATION: Provide sufficient general and/or local exhaust ventilation to maintain exposure below TLV(s). Use explosion-proof ventilation as required to control vapor concentrations below the TLV(s).

PROTECTIVE CLOTHING: Wear protective clothing as required to prevent skin contact.

PROTECTIVE GLOVES: Wear solvent-resistant gloves, such as butyl rubber.

EYE PROTECTION: Chemical splash goggles in compliance with OSHA regulations are advised; however, OSHA regulations also permit other type safety glasses. Do not wear contact lenses because they may contribute to the severity of an eye injury. (Consult your safety equipment supplier.)

OTHER PROTECTIVE EQUIPMENT: Solvent-resistant boots and headgear. Safety shower and eyewash.

K SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Store away from oxidizing materials, in a cool, dry place with adequate ventilation. Keep away from heat and open flames. Keep container tightly closed when not dispensing product.

Wash up with soap and water before eating, drinking, smoking or using toilet facilities. Launder contaminated clothing before reuse.

Containers of this material may be hazardous when emptied, since emptied containers retain product residues (vapor, liquid, and/or solid). All hazard precautions given in the Data sheet must be observed.

Ground equipment to prevent accumulation of static charge. Containers must be bonded and grounded when pouring or transferring materials.


OTHER PRECAUTIONS: Environmental Hazards - Keep out of surface water and watercourses or sewers entering or leading to surface waters.

DISCLAIMER:

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DATE OF PREPARATION: May 20, 1996

MATERIAL SAFETY DATA SHEET

 ProSoCo, Inc.

I PRODUCT IDENTIFICATION

MANUFACTURER'S NAME AND ADDRESS: ProSoCo, Inc.
P.O. Box 171677
Kansas City, Kansas 66117

EMERGENCY TELEPHONE NUMBER: 913/281-2700

PRODUCT TRADE NAME: T-1919 Conservare® OH Stone Strengtheners

II HAZARDOUS INGREDIENTS

CHEMICAL NAME	(COMMON NAME)	CAS NO.	NFPA CODE	ACGIH TLV/TWA	OSHA PEL/TWA
Tetra ethyl orthosilicate	(Ethyl Silicate)	78-10-4	2,2,0,-	10 ppm	10 ppm

III PHYSICAL DATA

	BOILING POINT (°F)	VAPOR PRESSURE (mm Hg)	VAPOR DENSITY (Air=1)	EVAPORATION RATE (1=Butyl Acetate)
Tetra ethyl orthosilicate	334	1.0 (68°F)	7.22	< 1

	SPECIFIC GRAVITY	SOLUBILITY IN WATER	APPEARANCE AND ODOR
T-1919 Conservare® OH Stone Strengtheners	0.920	Hydrolyzes in water	Clear colorless liquid, sweet odor

IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (METHOD): 125°F (51.66°C) (Cleveland Open Cup)

FLAMMABLE LIMITS: Not determined.

EXTINGUISHING MEDIA: Water fog, dry powder, foam or carbon dioxide extinguishing agents.

SPECIAL FIRE FIGHTING PROCEDURES: Prevent human exposure to fire, smoke, fumes, or products of combustion. Evacuate non-essential personnel from the fire area. Firefighters should wear full-face, self-contained breathing apparatus and impervious protective clothing. If possible, move containers from the fire area. If not leaking, keep fire-exposed containers cool with a water fog or spray to prevent rupture due to excessive heat. High pressure water may spread product from broken containers, increasing contamination or fire hazard.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Vapors are heavier than air and may accumulate in low areas or areas inadequately ventilated. Vapors may also travel along the ground to be ignited at location distant from handling site; flashback of flame to handling site may occur. Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively.

COMBUSTIBLE!!! Keep container tightly closed. Isolate from oxidizers, heat, and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions.

V HEALTH HAZARD DATA

PRIMARY ROUTES OF EXPOSURE: Inhalation and skin.

CARCINOGEN INFORMATION: Not listed (OSHA, IARC, NTP).

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: Asthma and inflammatory or fibrotic pulmonary disease. Person with pre-existing skin, liver, kidney, blood and/or chronic respiratory disease are at increased risk if exposed to this material.

EFFECTS OF OVEREXPOSURE: May cause damage to the liver and kidneys, and cause anemia.

EYE CONTACT: May cause irritation. 100 mg applied to rabbit eyes produced mild irritation.

SKIN CONTACT: Prolonged and/or repeated contact is expected to cause moderate irritation. Chronic dermal exposure effects are not known.

INHALATION: May irritate the respiratory tract and may cause central nervous system depression with dizziness, headache, or confusion.

Prolonged and/or repeated inhalation may cause severe respiratory irritation, pulmonary edema and possible kidney and liver damage.

INGESTION: May cause irritation to the mouth, throat, esophagus and stomach. May cause central nervous system depression with dizziness, headache, or confusion. May cause kidney and liver damage. The oral LD₅₀ for this material is 2,000 mg/kg in male rats. A single oral dose of 1,000 mg/kg did not produce signs of toxicity in male rats. Higher doses produced decreased physical activity, piloerection, excessive urination and mortality.

EMERGENCY AND FIRST AID PROCEDURES:

EYE CONTACT: If in eyes, flush with large amounts of water for 15 minutes, holding eyelids apart to ensure flushing of the entire eye surface. DO NOT let victim rub eye(s). Do not attempt to neutralize with chemical agents. Oils or ointments should not be used at this time. If persistent irritation occurs, get medical attention.

SKIN CONTACT: Wash with soap and water for at least 15 minutes. Remove contaminated clothing and do not reuse until laundered. If persistent irritation occurs, get medical attention.

INHALATION: Remove victim to fresh air and provide oxygen if breathing is difficult, preferably with a physician's advice. Give artificial respiration if not breathing. Get medical attention.

INGESTION: Give several glasses of water, but **DO NOT INDUCE VOMITING!** If vomiting does occur, give fluids again. Have medical personnel determine if evacuation of stomach or induction of vomiting is necessary. Do not give anything by mouth to an unconscious or convulsing person. Get immediate medical attention.

VI REACTIVITY DATA

STABILITY: Stable at ambient temperatures and atmospheric pressures. It is not self-reactive and is not sensitive to physical impact.

CONDITIONS TO AVOID: Under wet alkaline or acidic conditions, prolonged storage at elevated temperatures should be avoided to assure product integrity. Store away from foodstuffs, animal food and incompatibles such as oxidizers, acids and alkalis.

INCOMPATIBILITIES: This product hydrolyzes slowly and nonviolently under most alkaline or acidic conditions at ambient temperatures and atmospheric pressures to form silicon dioxide and ethanol. It reacts with oxidizing agents such as nitrates and hypochlorites. The product is slightly acidic and may attack certain plastics and corrode carbon steel over extended periods of time.

INCOMPATIBILITY (MATERIALS TO AVOID): Oxidizing materials, acids, and alkalis.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS: Thermal decomposition products include oxides of carbon, ethanol, and silicon dioxide.

VII SPILL OR LEAK PROCEDURES

SPILL, LEAK AND WASTE DISPOSAL PROCEDURES: STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Eliminate all sources of ignition in the area and stop the leak at the source. For large spills, dike ahead of spill to contain. For small spills absorb with sand, clay or other inert absorbent. Place in containers for disposal. Personnel involved in spill control and cleanup should follow the recommended exposure controls in SECTION VIII of this MSDS. All non-essential personnel should be evacuated from the immediate spill area.

WASTE DISPOSAL METHODS: Dispose of in a facility approved under RCRA regulations for hazardous waste. Containers must be leak-proof and properly labeled.

VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION: USE NIOSH-approved organic vapor respirators with dust, mist and fume filters to reduce potential for inhalation exposure if use conditions generate vapor, mist or aerosol and adequate ventilation (e.g. outdoor or well-ventilated area) is not available. Where exposure potential necessitates a higher level of protection, use a NIOSH-approved, positive-pressure-demand, air-supplied respirator. When working with respirator cartridges or canisters, they must be changed frequently (following each use or at the end of the work shift) to assure breakthrough exposure does not occur.

VENTILATION: Local exhaust ventilation, enclosed system design, continuous monitoring devices, process isolation and remote control are traditional exposure control techniques which may be used to effectively minimize employee exposure.

PROTECTIVE CLOTHING: Wear suitable protective clothing, gloves and footwear as required to prevent skin contact.

EYE PROTECTION: Selected with regard for use condition exposure potential. Do not wear contact lenses because they may contribute to the severity of an eye injury.

OTHER PROTECTION: Safety shower and eyewash.

IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Storage should meet the requirements of 29 CFR 1910.106, Flammable and Combustible liquids. Store in a cool, dry, well-ventilated area away from sources of heat, ignition, direct sunlight, oxidizers and alkalies. Keep container tightly closed when not dispensing product.

All food and smoking materials should be kept in a separate area away from the storage/use location. Eating, drinking and smoking should be prohibited in areas where there is a potential for significant exposure to this material. Wash up with soap and water before eating, drinking, smoking or using toilet facilities. Launder contaminated clothing before reuse.

Containers of this material may be hazardous when emptied, since emptied containers retain product residues (vapor, liquid, and/or solid). All hazard precautions given in the Data sheet must be observed.

Electrically grounded tanks and containers should always be used as should non-sparking, electrically grounded hand tools and appliances. Ground or bond to ground all vessels when transferring to prevent the accumulation of static electricity.

OTHER PRECAUTIONS: This product may attack certain plastics and could corrode carbon steel over extended periods of time. The preferred material of construction for use with this product is stainless steel. Maximum storage temperature 100°F (37.7°C).

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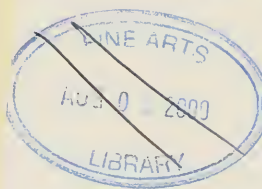
DATE OF PREPARATION: May 23, 1996

Anne & Jerome Fisher

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